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BIOENERGY TECHNOLOGIES OFFICE

2013 Bioenergy Market Report

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Preface

This report provides a status of the markets and technology development involved in growing a domestic bioenergy economy as it existed at the end of 2013. It compiles and integrates information to provide a snapshot of the current state and historical trends influencing the development of bioenergy markets. This information is intended for policy-makers as well as technology developers and investors tracking bioenergy developments. It also highlights some of the key energy and regulatory drivers of bioenergy markets. This report is supported by the U.S. Department of Energy's (DOE's) Bioenergy Technologies Office (BETO), and, in accordance with its mission, pays special attention to the progress and development of advanced liquid transportation fuels from cellulosic and algal biomass.

The bioenergy economy engages multiple industrial sectors across the biomass to bioenergy supply chain—from agricultural- and forestry-based industries that produce source biomass materials to manufacturers and distributors of biomass-based fuels, products, and power, to the ultimate end-user markets. The breadth of this report reflects the range of these interdependent industry sectors.

After opening with a discussion of the overall size and composition of the bioenergy market, this report features two major areas—one detailing biomass feedstocks supply and a second on the two major bioenergy markets: biofuels and biopower. The biomass feedstocks section brings together information about the current supply of a diverse set of feedstocks and discusses historical and current volumes for the major categories of biomass.

The biofuels section is broken out by fuel type with emphasis on ethanol, biodiesel, and hydrocarbon fuels (gasoline, diesel, and jet fuel). Ethanol includes conventional starch ethanol, as well as cellulosic ethanol. This report covers the development of the conventional ethanol industry as a backdrop for emerging cellulosic ethanol production, and discusses challenges with absorbing new production into the market. Hydrocarbon fuels include the fledgling renewable hydrocarbon biofuels market. The fuels section includes the status of advanced biofuels technology development and production of cellulosic ethanol and renewable hydrocarbon biofuels. Finally, the report offers an overview of the biopower market.

In total, the information contained in this report is intended to communicate a broad-based, cross-supply-chain understanding of the U.S. bioenergy market. As the inaugural report of nascent industries, there are known gaps. Future reports will focus on filling those gaps and expanding into related topics such as environmental impacts, production of bioproducts and biochemicals, and the effect of international markets. On behalf of the DOE and BETO, I hope that you explore and find value in this report.

Sincerely,
Jonathan L. Male
Director, Bioenergy Technologies Office
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

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Nomenclature

AD	anaerobic digestion
AEO	Annual Energy Outlook
AHJ	authorities having jurisdiction
ATJ	alcohol-to-jet
B5	5% biodiesel, 95% petroleum diesel blend
B20	20% biodiesel, 80% petroleum diesel blend
B100	pure biodiesel
BCAP	Biomass Crop Assistance Program
BDT	bone dry ton
BETO	Bioenergy Technologies Office
BMR	*2013 Bioenergy Market Report*
Btu	British thermal unit
BTU	*2011 Billion-Ton Update*
CAFE	corporate average fuel economy
CFR	Code of Federal Regulations
CHP	combined heat and power
DDG	dry distillers grains
DOE	U.S Department of Energy
E10	10% ethanol, 90% gasoline blend
E15	15% ethanol, 85% gasoline blend (approved for use in MY2001 and newer vehicles)
E85	high ethanol blend between 51% and 83% ethanol, depending on season and geography
E100	neat ethanol
EIA	U.S. Energy Information Agency
EISA	Energy Independence and Security Act of 2007
EPA	U.S. Environmental Protection Agency
FFV	flexible fuel vehicle
FT	Fischer-Tropsch
GDP	gross domestic product
gge	gallon gasoline equivalent
GHG	greenhouse gas
GWh	gigawatt hour
HEFA	hydrogenated esters and fatty acids
INL	Idaho National Laboratory
ISU	Iowa State University
LCOE	levelized cost of electricity
LFG	landfill gas
MMGY	million gallons/year
MSW	municipal solid waste
MTBE	methyl tertiary-butyl ether
MW	megawatt
MY	model year
NORA	National Oilheat Research Alliance
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
OSHA	Occupational Safety and Health Administration
OUST	Office of Underground Storage Tanks
R&D	research and development
RBOB	reformulated gasoline blendstock for oxygen blending
RFA	Renewable Fuels Association
RFS	Renewable Fuel Standard
RIN	Renewable Identification Number
RVO	renewable volume obligation
SKA	synthetic kerosene with aromatics
SPK	synthetic paraffinic kerosene
TBtu	1 trillion British thermal units
Ton	short ton
UL	Underwriters Laboratories
USDA	U.S. Department of Agriculture
USDA-ERS	U.S. Department of Agriculture Economic Research Service
USDA-FAS	U.S. Department of Agriculture Foreign Agriculture Service
USDA-FS	U.S. Department of Agriculture Forest Service
VEETC	volumetric ethanol excise tax credit

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Executive Summary

At the end of 2013, the U.S. bioenergy market (shown in Figure ES-1) was dominated by conventional starch ethanol production, which accounts for three-quarters of the total bioenergy production. Biodiesel and biopower make up nearly all the remaining production while renewable hydrocarbons contribute a relatively small amount. Various biomass feedstock resources are available in the United States that can be processed into electricity, heat, fuels, chemicals, and other bioproducts. This bioenergy market report focuses primarily on documenting the biofuels market in the United States as it existed at the end of 2013, with plans to expand the scope of this market report in future years.

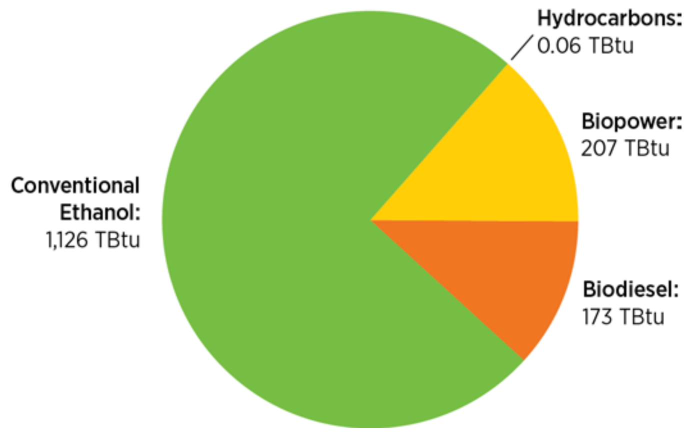

Figure ES-1. 2013 U.S. bioenergy production (1,506 TBtu total)

Sources: Conventional Ethanol, Biodiesel, and Biopower Production: U.S. Energy Information Agency (EIA) Annual Energy Review, Tables 10.2c, 10.3, 10.4, http://www.eia.gov/totalenergy/data/annual/index.cfm; Hydrocarbons: EPA-RFS2 2013. Note: This figure only includes the energy content of the product fuels and power, and not the associated co-products.

Biofuels make up the largest portion (approximately 86%) of the current bioenergy market. Figure ES-2 shows the development of the biofuels industry from 2004 to 2013. Production of all biofuels, especially ethanol, grew significantly during this time period after the enactment of the Renewable Fuel Standard (RFS) in 2005 as part of the Energy Policy Act of 2005 and later increased further under the Energy Independence and Security Act of 2007, which was enacted into law two years later. Crude oil prices during this time period also factored into the growth of biofuels production.

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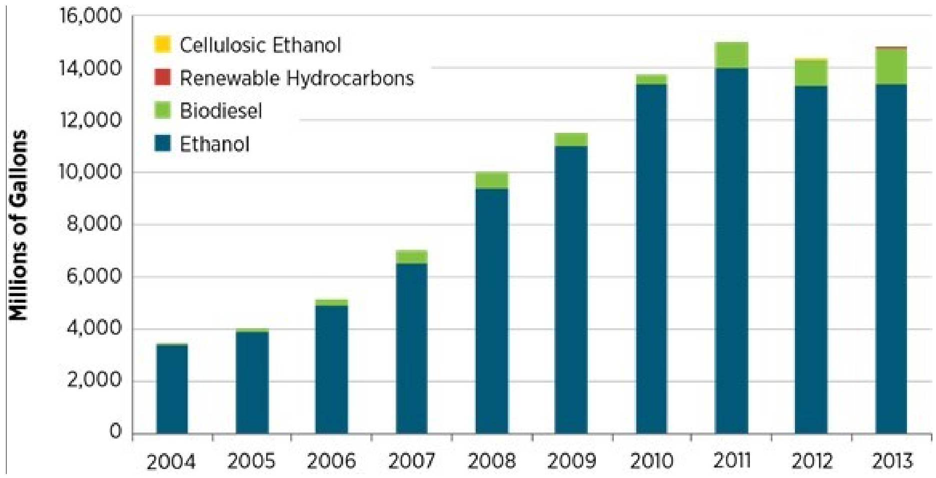

2012: cellulosic ethanol: 20,069 gallons, renewable hydrocarbons: 1,024 gallons; 2013: cellulosic ethanol: 0 gallons, renewable hydrocarbons: 514,627 gallons.

Figure ES-2. U.S. renewable fuels production

Sources: Ethanol and Biodiesel Production: EIA Annual Energy Review, Tables 10.3, 10.4, http://www.eia.gov/totalenergy/data/annual/index.cfm; Cellulosic Ethanol and Renewable Hydrocarbons: EPA-RFS2 2013.

Ethanol serves as a substitute for gasoline and as an octane enhancer. At the end of 2013, nearly all commercial ethanol biofuel production is from conventional corn starch-based feedstock. The cost of conventional ethanol is driven by the price of corn, production costs, and the sale of co-products such as distillers grains and influenced by gasoline prices. At current levels of use, the nation is essentially at a blend wall—where the entire market for E10 (a blend of 10 volume percent ethanol into a gallon of gasoline) is met with conventional ethanol. While there are more than 17 million flexible fuel vehicles on the road today that can use higher ethanol blends up to E85, a majority of those vehicles are refueling with E10 gasoline. Demand for ethanol could increase due to a 2011 U.S. Environmental Protection Agency approval of an increase to E15 blend for vehicles newer than 2001; however, retailers have been slow to adopt the newer blend due to liability and misfueling concerns.

While conventional ethanol is commercially successful using starch-based feedstock, the largest research and development push in the biofuels arena is for advanced biofuels made from cellulosic biomass and algae. To accommodate increased production from cellulosic ethanol biorefineries, the domestic ethanol market would need to grow or exports would need to increase because the RFS requirement for advanced cellulosic biofuels alone may not be enough to encourage investors given current market conditions such as reduced driving and more fuel efficient vehicles. During 2013, there was no commercial-scale production of cellulosic ethanol that resulted in the assignment of a renewable identification number.

Biodiesel production has generally increased during the past 10 years primarily driven by two policies—the RFS and biodiesel production tax credit. 2013 was the first year that biodiesel production and consumption exceeded the RFS requirement for biomass-based diesel due to favorable market conditions and a production tax credit. Because multiple feedstocks can be used for biodiesel production, the price of biodiesel is less dependent upon a single feedstock in

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contrast to the primarily corn-based conventional ethanol industry. This also allows biodiesel biorefineries to be built across a larger geographic area than conventional ethanol plants.

Renewable hydrocarbon biofuels—often referred to as "drop-in fuels"—are current-infrastructure compatible fuels produced from biomass sources through a variety of biological, chemical, and thermal processes. At the end of 2013, there was only one commercial facility (the KiOR facility in Columbus, Mississippi) producing renewable hydrocarbon biofuels. Another facility (the Dynamic Fuels, LLC facility in Geismar, Louisiana) was fully constructed, but was idle during 2013 due to market conditions. Despite mixed commercial success during 2013 for renewable hydrocarbon biofuels, development continues for biofuel products that can directly replace petroleum-based liquid transportation fuels.

In 2013, biopower accounted for 11% of all renewable energy produced in the United States and about 1.5% of total electricity generation. While the number of installed biopower facilities has increased from 485 in 2003 to 673 in 2012, combined electricity generation from these facilities has remained almost flat during that period.

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1 Biomass to Bioenergy Overview

Organic material that can be converted into bioenergy is known as biomass. Bioenergy—fuels and electricity derived from biomass sources—is an evolving market that can create secure and sustainable alternatives to fossil fuel sources. The following types of bioenergy were selected for inclusion in this inaugural bioenergy market report due to their market relevance at the end of 2013:

- Conventional ethanol—ethanol produced from starch in feedstocks (typically corn)
- Cellulosic ethanol—ethanol produced from cellulosic biomass, such as agricultural residues and woody resources
- Biobutanol—an alcohol that can be used as a fuel or fuel additive currently produced from starch sources
- Biodiesel—an alternative to diesel that is typically produced from lipids
- Renewable hydrocarbon biofuels—diesel, jet fuel, and gasoline replacements, produced from various sources such as cellulosic or algal biomass, that can be transported and used within the current liquid fuels infrastructure
- Biopower—generation of electricity from biomass sources
- Bioproducts and co-products—for this report, considered as co-products that are produced in conjunction with biofuels that enable bioenergy production. Future reports will include expanded coverage of the bioproducts category.

Production, distribution, and use of bioenergy involve activities across a broad supply chain. This includes the production of the raw biomass in field or forest, harvest, collection, storage, and transportation of these materials, and preprocessing the raw biomass materials—sizing, drying, or other mechanical, thermal, or chemical treatment— to produce a feedstock that can be fed into biorefinery conversion processes or into biopower generating facilities. It also includes distribution of the resulting biofuels, bioproducts, or biopower to end-use markets and the ability of those end-use markets to use those products.

The primary market driver for advanced biofuels production and consumption is the Renewable Fuel Standard (RFS). The RFS is a federal program that requires transportation fuel sold in the United States to contain a minimum volume of renewable fuels. The RFS contains requirements for qualification of biomass under RFS program regulations. Thus, the total domestic biomass resource is not available for production of qualified biofuels under the RFS program. Even if a feedstock qualifies under the biomass provisions of the RFS program, there may not be a fuel conversion pathway under the RFS program to allow for qualification with the life-cycle greenhouse gas (GHG) requirements. From a regulatory perspective, these requirements must also be met to produce an RFS-qualified biofuel. While the bioenergy market is global and well established in other parts of the world, only the U.S. market was investigated and documented for this 2013 market report.

In 2013, U.S. bioenergy production surpassed 1,500 trillion Btu from ethanol, biodiesel, renewable hydrocarbons, and biopower (EIA 2014a; EPA-RFS2 2013). A comparison of the contributions of biofuels and biopower to bioenergy production in 2013 is shown in Figure 1.

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Conventional starch ethanol production accounts for nearly three-fourths of total bioenergy production. At current levels of ethanol use, the United States is essentially at a blend wall—where the entire market for E10 (a blend of 10 volume percent ethanol and 90 volume percent gasoline) is met with conventional ethanol. Scenarios exist for moving beyond this blend wall; however, current market forces, regulatory application, and policy limit the rate at which ethanol can be blended with gasoline. This in turn limits demand for ethanol at a level that can be met with existing, conventional ethanol production volumes.

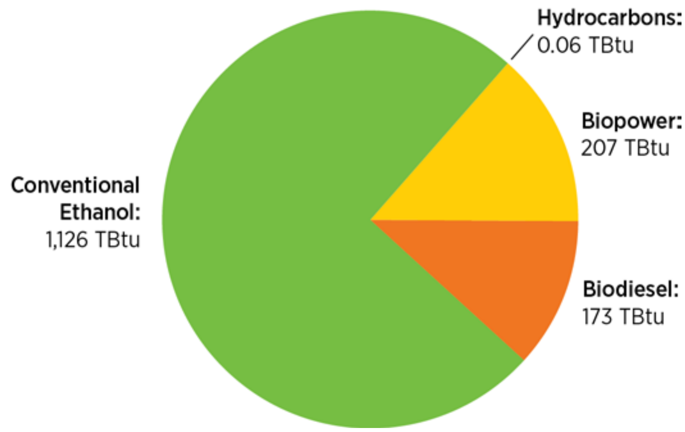

Figure 1. 2013 U.S. bioenergy production (1,506 TBtu total)

Sources: Conventional Ethanol, Biodiesel, and Biopower Production: U.S. Energy Information Agency (EIA) Annual Energy Review, Tables 10.2c, 10.3, 10.4, http://www.eia.gov/totalenergy/data/annual/index.cfm; Hydrocarbons: EPA-RFS2 2013. Note: This figure only includes the energy content of the product fuels and power, and not the associated co-products.

2 Feedstock

2.1 Feedstock Overview

In the United States various biomass resources are available that can be converted into electricity, heat, fuels, chemicals, and other products. These resources include:

- Starch crops such as corn and barley
- Cellulosic material such as forest biomass, wood waste (e.g., municipal solid waste [MSW] wood), and crop residues
- Lipids such as vegetable oils and animal fats
- Algae, a large group of plant-like photosynthetic organisms
- Biomethane, which is upgraded biogas from wastewater, landfills, animal manure, and other organic wastes.

Table 1 represents a 2012 snapshot of total available and currently-used biomass resources in the United States, compiled from the best available data (in some cases, datasets from previous years were used if it was the most complete or current dataset available.) Forward-looking and projected biomass availability data is available in the *U.S. Billion-Ton Update* (USDOE 2011).

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For reference, Appendix A provides a comparison of some of the feedstock data presented in the *U.S. Billion-Ton Update* with data presented in this market report.

Detailed information regarding specific feedstocks used in the production of biofuels and biopower is presented later in this report. This report captures most MSW components in other feedstock categories, with the exception of paper and cardboard, which will be addressed in future market reports. Additionally, future market reports will attempt to incorporate known missing information (such as amounts of agricultural crop residues used in bioenergy applications) and increase the rigor of data quality as updated and improved datasets become available. Subsequent reports may also include feedstock market prices, which were out of scope for this report, but could provide more complete resource information in the future.

As illustrated in Table 1, cellulosic biomass is the most abundant bioenergy resource, estimated at about 400 million bone dry ton (BDT) annually, more than 50% of which is woody material. As such, cellulosic biomass represents a significant opportunity for producing bioenergy if market conditions are favorable, and the resource can be coupled with an appropriate conversion technology.

Table 1. U.S. Annual Biomass Resources (2012)

Feedstock	Total (million tons)	Current Use (million tons)			
		Bioenergy	Food	Animal Feed	Other
Starch-based	302[1]	130[7]	6[7]	121[7]	54[7]
Lipid-based	18[2]	4[8]	11[8]	1[8]	2[8]
Total cellulosic biomass (BDT)					
Agricultural crop residues	150[3]	-	n/a	-	-
Forest resources	235[4]	73[9]	n/a	n/a	50[10]
Other herbaceous	15[5]	-	n/a	n/a	9[5]
Biomethane	9[6]	-	n/a	n/a	-

Other uses include export, chemicals, fiber products, recovery through composting, etc.
n/a = not applicable.
"-" = information not available, to be provided in future versions of this market report.
In few cases, datasets from previous years were used if it was the most complete or current dataset available.

[1] Total corn grain production in 2012/13. It does not include carry-over and import, which provide additional supply. Data source: USDA-ERS 2014a.

[2] Includes total production of select vegetable oils (soybean oil, canola oil, sunflowerseed oil, cottonseed oil, and corn oil), animal fats, and greases in 2012. It does not include carry-over and import, which provide additional supply. Data sources: USDA-ERS 2014b and Swisher 2014.

[3] Includes harvesting and processing agricultural crop residues produced in 2012. Harvesting residues account for 35% of total agricultural crop residues. Data sources: harvesting crop residues—USDA 2014 and Milbrandt 2005; and processing crop residues—Eaton 2014.

[4] Forest resources include 65% of logging residues (2012), 50% of other removals (2012), total primary mill residues (2012), urban wood waste (2012), secondary mill residues (2012), 20% of pulpwood (2012), black liquor (2010), standing dead timber (assuming harvest over a 30-year period), and 50% of thinnings from pinyon-juniper woodland (assuming harvest over a 30-year period). Data sources: USDA-FS 2014a; NREL 2014a; Skog et al. 2013; USDOE 2011; Prestemon et al. 2013; and USDA-FS 2014b.

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Biomass is a renewable and, generally speaking, widely available and accessible resource, amenable to conversion to bioenergy. However, biomass varies substantially in its composition, energy content, and physical characteristics, which presents many technical challenges in the conversion processes and can have a large impact on conversion costs. For example, corn stover, the most abundant agricultural crop residue available in the U.S. market, can range from 10% moisture content to more than 45% moisture content depending on harvest year, weather during harvest, and harvest and collection techniques (Kenney et al. 2013). For certain bioenergy production processes, higher moisture biomass may require drying, resulting in higher bioenergy production costs. In addition, corn stover has variable ash and carbohydrate content due to soil, climate, and growing conditions.

Competing uses, the cost of collection and transportation, and ecological factors such as soil erosion, limit the amount of cellulosic biomass that is available for energy production. Agricultural crop residues are mostly underutilized, although a small portion of this resource is used for power generation and other applications. About 52% of the forest resources identified in this study are being used for power generation, heating, fiber products, in the manufacture of pellets, for export, and in other applications (Table 1). About 58% of yard trimmings, nationally, are composted (EPA 2014). If priced competitively with other end-use markets, some of these resources could be used for the production of bioenergy.

In addition to competing uses, the cost of collection and transportation also limits the amount of biomass that is available for energy production. Abundance of a certain resource does not necessarily mean that it can be cost-effectively collected and used for bioenergy. For example, pinyon-juniper woodland thinnings in western states are physically available but may be very expensive to remove given their low density per acre. Similarly, the beetle-killed timber in the West is a large resource, but some stands are inaccessible because they are too remote or on terrain that is too costly to access and harvest.

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[5] Other herbaceous biomass includes yard trimmings collected in 2012, of which 58% were composted. Data source: EPA 2014.

[6] Includes biomethane potential from animal manure, landfills, wastewater, and other organic wastes (e.g., food waste). Data source: NREL 2013.

[7] Bioenergy use of corn includes ethanol production (2012/13). Food use includes the production of cereals. Animal feed includes corn grain (not dry distillers grain) used as feed and residual corn (e.g., grain in transit). Other uses include corn used for the production of high-fructose corn syrup, glucose and dextrose, starch, alcohol for beverages/manufacturing, and export. All data is for crop year 2012/13. Data source: USDA-ERS 2014a.

[8] Bioenergy use of lipid-based feedstock includes biodiesel production (2012). Food use includes the production of baking or frying fats, margarine, cooking oil, etc., in 2010. Data on lipids used for animal feed is from 2010. Other uses of lipid feedstock include export (2012) and inedible products (e.g., fatty acids, lubricants, paint, and soap) in 2010. The data on consumption of lipids for food, feed, and inedible products from 2010 is applicable to 2012 because these industries have shown similar level of lipids use over the years. Data sources: EIA 2014b; US Census Bureau 2014; USDA-ERS 2014b; and Swisher 2014.

[9] Forest resources currently used for bioenergy include primary mill residues (26 million dry tons, 2012), black liquor (45 million dry tons, 2010), and MSW wood (1.9 million dry tons, 2012). Data sources: USDA-FS 2014c; USDOE 2011; and EPA 2014.

[10] Other uses of forest resources include wood chips/particle export (2.5 million dry tons), primary mill residues used for fiber and other products (33 million dry tons), and pulpwood (15 million dry tons). Data sources: FAO 2014; USDA-FS 2014c; and Skog et al. 2013.

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There are also ecological reasons for limited biomass availability. For some resources, such as crop and logging residues, a certain portion of the material needs to remain on the field to maintain soil quality and other ecological functions. In the case of beetle-killed timber that has been standing for some time, harvesting may be prohibited in certain areas because it could damage growth of new trees (Hein 2010).

2.2 Starch-Based Feedstock

Starch crops used in bioenergy production (starch ethanol) include primarily corn as well as small volumes of other crops such as grain sorghum, barley, and wheat.

The United States is the world's largest corn producer. Corn is grown in most states but production is primarily concentrated in Iowa, Minnesota, Nebraska, North Dakota, and Illinois (USDA 2014). Corn is the primary U.S. feed grain, accounting for more than 90% of total feed grain production and use (USDA-ERS 2014a). Corn is also processed into a wide range of food and industrial products. In crop year 2012/13[11], corn used for ethanol accounted for about 43% of total production (Figure 2).

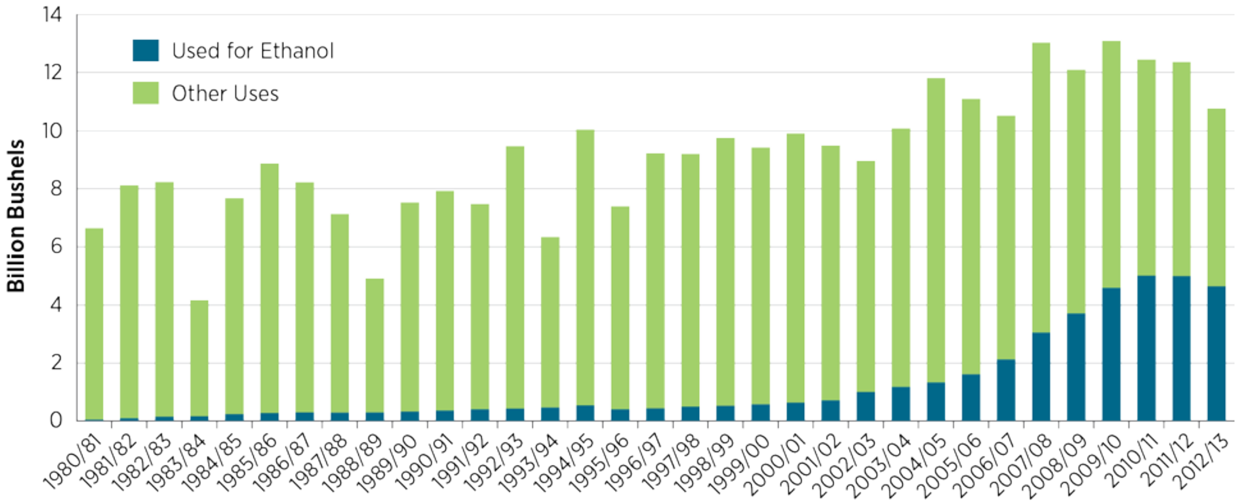

Figure 2. U.S. corn production and use for fuel ethanol

Source: USDA-ERS 2014a.

The United States is a major player in the world corn trade market, with approximately 20% of the corn crop exported to other countries (USDA-ERS 2014a). In the past, U.S. corn accounted for about 50%–75% of world corn exports, but over the last few years the United States has lost its corn-export dominance. Several years of historically high prices encouraged production expansion in other countries, particularly Brazil and Ukraine (USDA-ERS 2014c). Severe and extensive drought in the United States during 2012 resulted in low supply and high prices, which prompted traditional U.S. corn importers to look elsewhere. Resistance by some importing countries to genetically modified corn and dried distillers grains (DDG) is an emerging issue.

[11] September–August.

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The drought in 2012 also led to an unprecedentedly high level of corn imports, which historically had been very small.

2.3 Lipid-Based Feedstock

Lipid-based feedstock includes vegetable oils, animal fats, and greases. For bioenergy, it is primarily used to produce biodiesel but is also used to produce hydrocarbon fuels, namely renewable diesel and jet fuel. The total U.S. production of vegetable oils, animal fats, and greases used in biofuels production is estimated at about 18 million tons in 2012 and this has been the annual production rate over the past several years (USDA-ERS 2014b; Swisher 2014; Milbrandt et al. 2013).

Vegetable oils used in biofuels production (mainly biodiesel) include oils from soybean, corn, canola, sunflowerseed, cottonseed, and camelina. Soybean oil production, the largest contributor, has been relatively consistent over the past 10 years, about 9–10 million tons annually (USDA-ERS 2014b). The United States is the world's largest producer of soybeans and the second largest producer of soybean oil, after China (USDA-FAS 2014). Given that soybean is used primarily in crop rotation with corn, its production regions follow those of corn (primarily the Midwest) and soybean crushing facilities are typically located near production areas. Biodiesel production used about 27% of the soybean oil produced in 2013 (EIA 2014b; USDA-ERS 2014b).

Corn oil production was about 1.3 million tons in 2012 (USDA-ERS 2014b). Its use for biofuel production has increased between 2011 and 2013. Historically, corn oil has not been a viable biofuel feedstock due to its relatively high cost and high value as edible oil. However, in the last few years, many ethanol plants (in response to difficult market conditions) have been adding technology to remove corn oil from distillers grains and solubles, thus generating an additional income stream that improves their profit margins (AgMRC 2013). This technology produces lower quality corn oil that typically is not suitable for the food industry and it is largely used as a biodiesel feedstock or as an energy source in livestock and poultry diets.

Canola oil production was about 595,000 tons in 2012 (USDA-ERS 2014b). It was the second largest biofuel resource during 2011 and 2012, but it fell to lower levels in 2013 (EIA 2014b). The reduction was due to an increased use for canola oil as a partial replacement for soybean oil in the food industry and due to the increasing use and availability of less expensive feedstock for biofuel such as animal fats, waste greases (e.g., yellow greases), and low-quality corn oil.

Small amounts of sunflowerseed and cottonseed oils also are used as feedstock and camelina, a member of the mustard family, has been explored as an alternative biofuel feedstock.

Animal fats are another lipid-based biofuel feedstock category. This category includes tallow (beef fat), white grease (derived from pork tissue), poultry fat, and other animal fats. Animal fats production has been relatively consistent during the past several years. Inedible tallow is the largest resource within this category with more than 1.6 million tons produced in 2012, followed by edible tallow with about 895,000 tons, white choice grease with 585,000 tons, and poultry fat with about 523,000 tons (Swisher 2014).

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The use of yellow grease (derived from used cooking oil) and other recycled feeds for biofuels production has been on the rise during the last few years due to low cost and wide availability of the resource. Yellow grease production has been relatively consistent during the past several years with about 1 million tons produced annually (Swisher 2014). Brown grease (waste grease recovered from traps installed in drains at restaurants, food processing plants, and wastewater treatment plants) is another lipid-based feedstock; but, its quantity is not systematically estimated, and thus this resource potential is not well understood.

The United States is a major player in the global oils and fats market. The United States was the leading exporter of soybeans until 2012–2013 when it lost its dominance to Brazil (USDA-FAS 2014). Other major exporters of soybeans are Argentina and Paraguay with China and the European Union as major destinations. Soybean oil is exported primarily from Argentina, followed by Brazil, the European Union, and the United States. Major destinations are India and China. The U.S. export of inedible tallow has been declining in recent years due to increased local use (Swisher 2014). Yellow grease export was on the rise during 2010 and 2011 but it has been declining since then because of the increased domestic consumption for biofuels production (Swisher 2014).

2.4 Cellulosic Feedstock

Cellulosic biomass resources can be generally classified into three categories: agricultural crop residues, forest resources, and dedicated energy crops. These biomass resources are used to generate electricity, power, and various biofuels such as cellulosic ethanol and renewable hydrocarbon biofuels. Table 2 illustrates the cellulosic biomass resources in the United States. It also shows the total biomass resource that was generated in 2012, not the biomass resource available for conversion to bioenergy, and does include materials that are currently utilized (namely primary mill residues and black liquor).

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Table 2. U.S. Annual Cellulosic Biomass Resources (2012)

Biomass Resource	Annual Generation (million BDT)
Total agricultural crop residues	***150***
Harvesting crop residues [12]	138
Processing crop residues [13]	12
Total forest resources	***235***
Logging residues [14]	32
Other removals [14]	11
Primary mill residues [15]	60
Urban wood [16]	45
Secondary mill residues [17]	10
Standing dead timber [18]	9
Thinnings from pinyon-juniper woodland [19]	8
Conventionally sourced wood (pulpwood) [20]	15
Black liquor [21]	45
Total other herbaceous	***15***
Yard trimmings [22]	15
Total cellulosic biomass	***400***

[12] Harvesting crop residues are estimated for corn, wheat, grain sorghum, rice, barley, oats, sugarcane, and cotton in 2012. The analysis accounts for 35% of the total harvesting crop residue; the remaining residue is left on the field to maintain ecological and agricultural functions. Data sources: USDA 2014 and Milbrandt 2005.

[13] Processing crop residues include rice hulls, cotton gin trash, sugarcane bagasse, soybean hulls, wheat dust and chaff, and orchard and vineyard prunings. This estimate is based on crop production, crop-to-residue ratio, and the export amount for 2013. Data source: Eaton 2014.

[14] Logging residues account for 65% of total (2012). Other removals account for 50% of total (2012). The remaining portion is left on the field to maintain ecological functions. Data source: USDA-FS 2014a.

[15] Total primary mill residues (used and unused) generated in 2012. Most of the material is currently used for fuel, fiber products, or in other applications, but it is included here as this table summarizes all biomass resource generated annually. Data source: USDA-FS 2014a.

[16] Urban wood waste includes the woody component of MSW, construction and demolition waste wood, and tree trimmings from utilities or private tree companies generated in 2012. Data source: NREL 2014a.

[17] Secondary mill residues include wood scraps and sawdust from woodworking shops—furniture factories, wood container and pallet mills, and wholesale lumberyards generated in 2012. Data source: NREL 2014a.

[18] Standing dead timber accounts for about 262 million dry tons available over many years. We assume that this resource could be harvested over a 30-year period, which is about 8.7 million dry tons annually. Data source: Prestemon et al. 2013.

[19] Thinnings from pinyon-juniper woodland account for 50% of the total (about 448 million dry tons), which is about 224 million dry tons available over many years. We assume that this resource could be harvested over a 30-year period, which is about 7.5 million dry tons annually. Data source: USDA-FS 2014b.

[20] Pulpwood accounts for 20% of roundwood harvesting for pulp and paper production. Data source: Skog et al. 2013.

2.4.1 Agricultural Crop Residues

Agricultural crop residues are divided into two sub-categories: harvesting crop residues and processing crop residues. Harvesting crop residues, also called field residues, are materials such as leaves, stalks, straw, and stubble left on the field after crop harvesting. Processing crop residues include materials left after the crop has been processed into a primary product. These residues include husks and bagasse.

Harvesting crop residues are the most abundant fraction of agricultural crop residues. The quantity of harvesting crop residues is estimated using crop production data from USDA's 2012 Census, crop-to-residue ratio, accounting for moisture content, and taking into consideration the amount of residue left on the field for soil protection, grazing, and other agricultural activities (Milbrandt 2005). Estimated harvesting crop residues in 2012 were about 138 million dry tons, which has been relatively consistent over the past years (Figure 3). This estimate assumes an aggregate average removal of only 35% of the total residue that could be collected as biomass while the remaining residue is left on the field to maintain ecological and agricultural functions (Walsh et al. 2000). The estimate of harvesting crop residues includes corn, wheat, grain sorghum, rice, barley, oats, sugarcane, and cotton. Harvesting crop residues are concentrated primarily in the Midwest and along the Mississippi River (Figure 4). Note that the quantity of crop residues that must remain on the field depends on many factors including the crop type, soil type, erosion type (wind or water), climate conditions, and field management practices. In reality, the retention rate is not a fixed percentage but a range. Thus, in a specific area the amount of residues that could be collected as biomass could be more or less than the 35% assumed here. This analysis uses a conservative value of 35% for illustrative purposes only, and it is suggested that more detailed analyses be conducted in planning and siting efforts. Recent research on the sustainable retention rate by academia and national laboratories could support further, more in-depth analyses (Bonner et al. 2014a; Muth and Bryden 2013; Graham et al. 2007; Nelson et al. 2004; Nelson 2002).

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[21] Black liquor, or pulping liquor, is a by-product of the pulping processing technology used in the manufacture of paper products. This resource is largely used by the pulp and paper mills to produce heat and power but it is included here as this table summarizes all biomass resource generated annually. Data source: USDOE 2011.
[22]Yard trimmings (grass clippings, leaves, and tree/brush trimmings) collected in 2012. Data source: EPA 2014.

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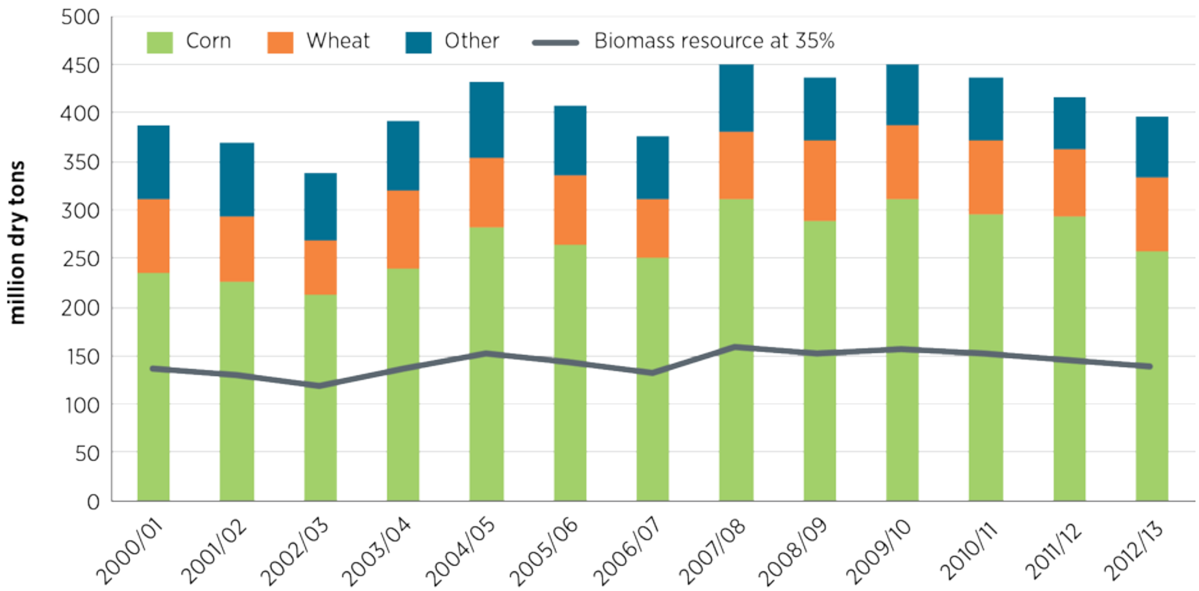

Figure 3. U.S. harvesting residues from major crops

Other crops include grain sorghum, rice, barley, oats, sugarcane, and cotton. Source: USDA 2014.

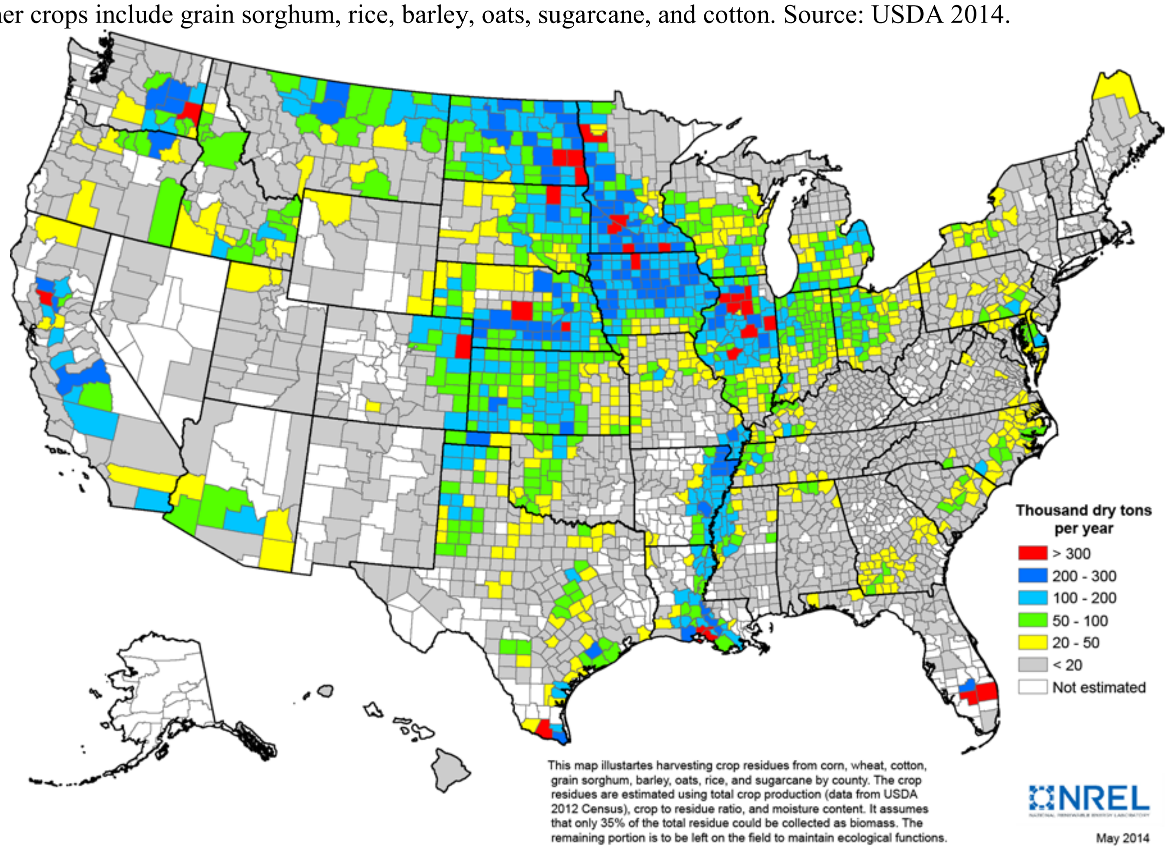

Figure 4. Harvesting residues from major crops by county in 2012

Processing crop residues were estimated at roughly 16 million dry tons in 2013 and include rice hulls, cotton gin trash, sugarcane bagasse, soybean hulls, wheat dust and chaff, and orchard and

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vineyard prunings. This estimate was based on crop production, crop-to-residue ratio, and the export amount for 2013 (Eaton 2014).

2.4.2 Forest Resources

Forest resources include logging residues and other removals, primary and secondary mill residues, urban wood, standing dead timber, thinnings from pinyon-juniper woodlands, conventionally sourced wood (pulpwood), and black liquor.

Logging residues are defined by the U.S. Department of Agriculture Forest Service (USDA-FS) as the unused portions of trees cut or trees killed by logging that are left in the woods after harvesting operations (USDA-FS 2014d). Other removals are defined as the unutilized wood volume of trees cut or otherwise killed by silvicultural operations (e.g., pre-commercial thinnings) or land clearings to non-forest uses (USDA-FS 2014d). While the volume of logging residues has fluctuated over the inventory years, the volume of other removals has remained fairly consistent (Figure 5). Estimated production of wood from logging residues and other removals in 2012 was about 48 million dry tons and 21 million dry tons, respectively. It is assumed that about 65% of logging residues and 50% of other removals are physically available. The remaining portion is to be left on site to maintain ecological functions (Skog 2014; USDOE 2011). Thus, the amount of these resources is reduced to about 32 million dry tons for logging residues and 11 million dry tons for other removals. Figure 6 illustrates the geographic distribution of these resources with the Southeast, Northwest, Upper Midwest, and Northeast as the main producing regions.

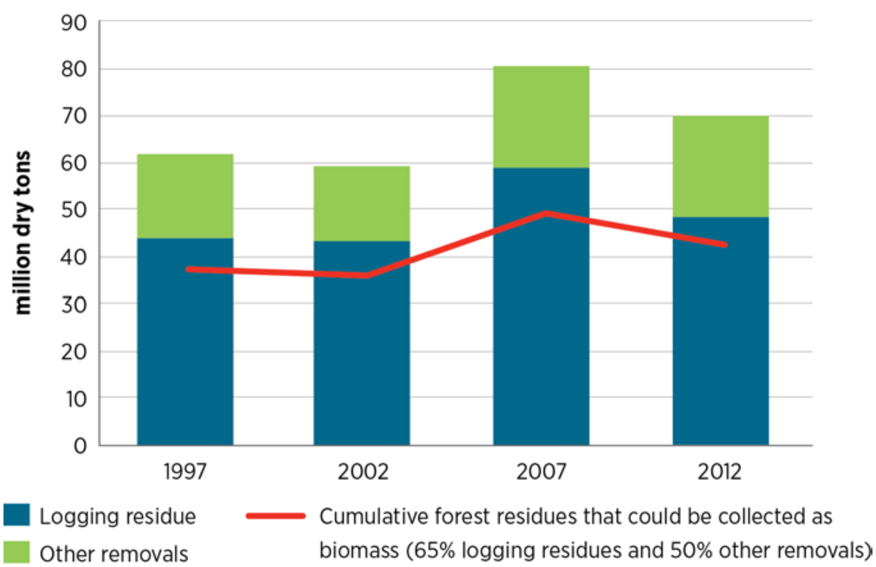

Figure 5. U.S. logging residues and other removals

Source: USDA-FS 2014a.

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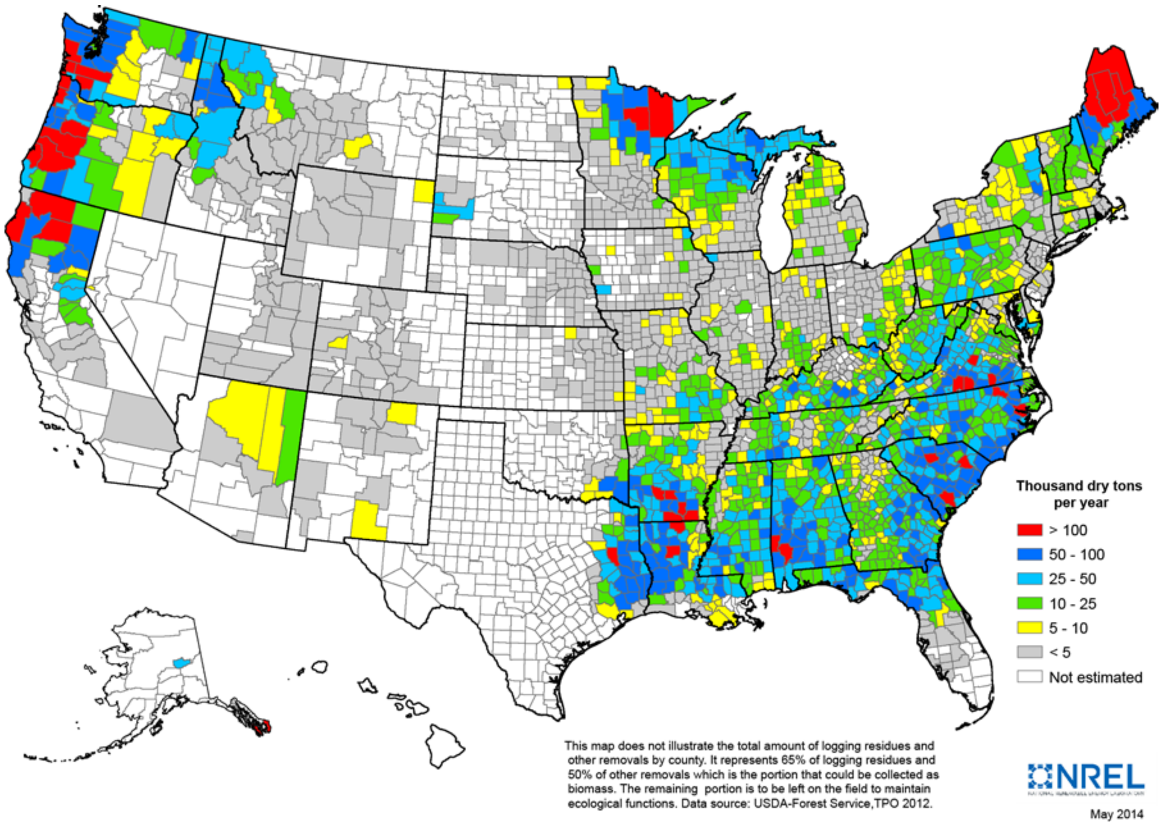

Figure 6. Logging residues and other removals by county in 2012

Primary mill residues are wood materials generated at manufacturing plants (primarily wood-using mills) when roundwood is processed into primary wood products (USDA-FS 2014d). Generation of primary mill residues has declined in recent years due to the closing of sawmills or improved technology for minimizing waste (Figure 7); the estimated amount in 2012 was about 60 million dry tons. Most of the material is used for fuel, fiber products, or in other applications. Some of the mill residue used for low-value uses, such as mulch, could be shifted to bioenergy applications (Skog et al. 2013). Figure 8 illustrates the geographic distribution of primary mill residues with the Southeast, Northwest, and Upper Midwest as the main producing regions.

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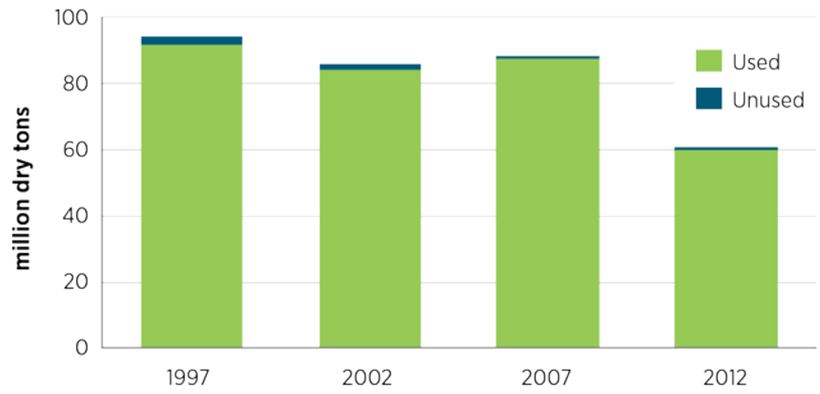

Figure 7. U.S. primary mill residues

Source: USDA-FS 2014a.

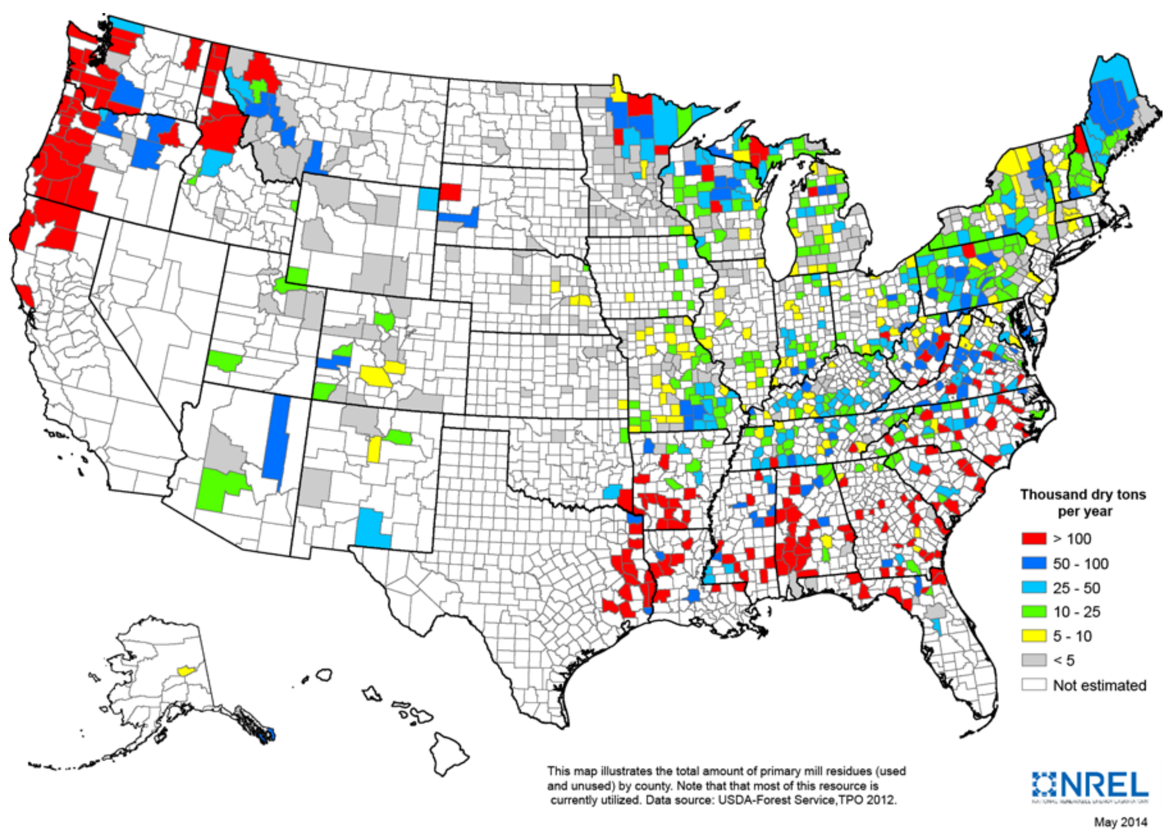

Figure 8. Primary mill residues by county in 2012

Sources of urban wood waste include the woody component MSW, construction and demolition waste wood, and tree trimmings from utilities or private tree companies. It is estimated that about 45 million dry tons of urban wood waste were generated in 2012, and were concentrated primarily in populated areas (Figure 9) (NREL 2014a). The analysis is based on 2012 population data (ESRI 2013), MSW per capita by state (*BioCycle* 2010), number of relevant business

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establishments by county from the U.S. Census Bureau’s 2012 County Business Patterns, and assumptions adopted from Milbrandt 2005.

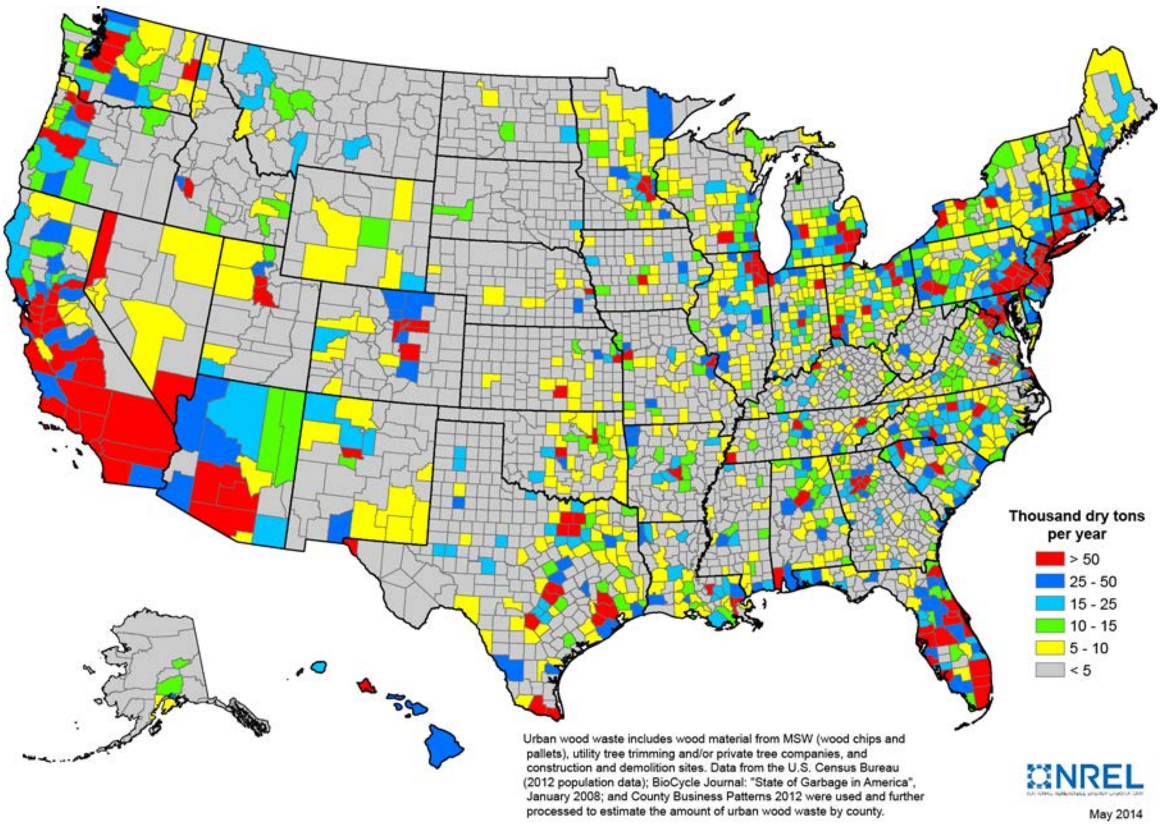

Figure 9. Urban wood waste by county in 2012

Secondary mill residues include wood scraps and sawdust from woodworking shops—furniture factories, wood container and pallet mills, and wholesale lumberyards. These resources were estimated at about 10 million dry tons in 2012 (NREL 2014a). The analysis is based on the number of relevant business establishments by county from the U.S. Census Bureau’s 2012 County Business Patterns and assumptions adopted from Rooney (1998). Similar to urban wood waste, secondary mill residues generation follows population concentrations (NREL 2014b).

A study by the USDA-FS (Prestemon et al. 2013) estimates the volume of standing dead timber (mountain pine beetle timber) available for salvage in the Western United States. The resource potential is estimated at more than 260 million dry tons, distributed across 20.3 million acres in 12 Western states. This resource is available over many years, but for this analysis we assume that it could be harvested over a 30-year period, which is about 9 million dry tons annually. The most heavily affected states are in the interior West: Colorado, Idaho, Montana, and Wyoming. One of the key conclusions of the USDA-FS report is that some salvage in California, Oregon, Washington, Idaho, South Dakota, and Montana could generate positive net revenues, on both private and public lands, and across a wide range of potential salvage intensities. However, salvage would not generate positive net revenues in the interior western states of Arizona, New Mexico, Utah, Colorado, Nevada, and Wyoming; although, simulations of a hypothetical doubling of demand in Colorado show smaller revenue losses.

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Pinyon-juniper woodlands cover large areas of the Western United States. These woodlands are heterogeneous, consisting of various combinations of tree, shrub, and herbaceous species (primarily pinyon pine and regionalized juniper). Many of these woodlands are overstocked and thinning for removal of the excess biomass is seen as an opportunity to greatly reduce fire hazards (USDOE 2011). The available above-ground biomass on pinyon-juniper woodland is estimated at about 224 million dry tons, which is 50% of the total wood resource (about 448 million dry tons) (USDA-FS 2014b). Similar to standing dead timber, this resource is available over many years but for this analysis we assume that it could be harvested over a 30-year period, which is about 8 million dry tons annually. Because the density of biomass per acre is low, harvesting costs would be high.

Conventionally sourced wood, or pulpwood, refers to timber used primarily in the pulp and paper industry and also to make oriented strandboard. While currently utilized, this resource could be used for bioenergy if priced competitively with other end-use markets (Skog et al. 2013). Skog et al. (2013) estimates the minimum amount that could be supplied at about 15 million dry tons, which is about 20% of the annual roundwood harvest used as pulpwood. This is the amount by which the annual pulpwood harvest has declined over the last decade.

Black liquor, or pulping liquor, is a by-product of the pulping processing technology used in the manufacture of paper products. It is an aqueous solution of lignin residues, hemicellulose, and other chemicals. The amount of black liquor resin generated in the pulp and paper industry is estimated at about 45 million dry tons (USDOE 2011). However, it is largely used by the pulp and paper mills to produce heat and power.

2.4.3 Energy Crops

Dedicated energy crops include herbaceous and woody resources.

Herbaceous energy crops are perennial grasses and some annual crops grown purposely for bioenergy production. Perennial herbaceous energy crops suitable for the U.S. agroclimatic conditions include switchgrass, miscanthus, energy cane, giant reed, reed canary grass, napier grass/elephant grass, big bluestem, Indian grass, prairie cordgrass, prairie sandreed, and erianthus. Annual crops include sorghum hybrids—sweet sorghum and dedicated biomass sorghum.

Switchgrass, miscanthus, and sorghum hybrids are the most studied and evaluated crops. Switchgrass has been identified as a model herbaceous perennial feedstock due to a number of distinct benefits including broad adaptation, improved soil conservation and quality, reduced greenhouse gas emissions, carbon sequestration, high yield potential on marginal lands, cover value for wildlife, and easy integration into conventional farming operations (Bonner et al. 2014b; Sun Grant 2011; Lewandowski et al. 2003). Miscanthus has become the subject of renewable energy research because it produces more biomass compared to other crops adapted to temperate regions (Sun Grant 2011). Sorghum has been identified as a highly productive, drought tolerant biomass crop and its productivity begins in the year that the crop is planted, thus there is no establishment year (Sun Grant 2011).

There is limited commercial production of herbaceous energy crops in the United States, but there are field trials around the country. The U.S. Department of Agriculture (USDA) reports

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that about 1,169 acres with sweet sorghum were harvested in 2012 (USDA 2014). Roughly 3,000 switchgrass acres were harvested that year and production level was at about 11,800 green tons. Most of these operations are located in Tennessee, with some in Pennsylvania, Oklahoma, and a few other states. Field trials of miscanthus are concentrated in Illinois, Michigan, Mississippi, and Missouri.

Woody energy crops include trees grown specifically for industrial purposes, e.g., fiber and bioenergy production. Short-rotation woody crops for biomass production include eucalyptus, poplar, pine, and willows. Poplars and willows are suitable for the northern states, pines and poplars for the southern states, and eucalyptus is suitable for the southeastern Atlantic and Gulf of Mexico coastal regions. Commercial plantings of these crops have been established in the United States for fiber use. It is estimated that more than 100,000 acres of hybrid poplar and more than 700 acres of willow are planted in the country (FAO 2012), primarily in the Pacific Northwest, the Midwest, and the Southeast. Nearly 30,000 acres of eucalyptus are being grown in Hawaii and across the Southeast (eXtension 2013).

2.4.4. Other Herbaceous Biomass

Additional herbaceous biomass sources include yard trimmings. Yard trimmings are a category of MSW and include grass clippings, leaves, and tree/brush trimmings. In 2012, yard trimmings accounted for 13.5% of total waste generated that year, or about 34 million green tons (roughly 15 million dry tons, assuming 55% moisture content) of which about 58% were composted (EPA 2014).

2.5 Other Biomass

Other biomass feedstocks include algae and biomethane. The term "algae" refers to a large group of plant-like photosynthetic organisms—from microscopic cyanobacteria to giant seaweed. Algae are a potential aquatic oil crop, but may also yield carbohydrates that can be converted to sugar, thus they can be used to produce a variety of biofuels. Given the right resources—suitable climate, availability of water, carbon dioxide, and other nutrients—algae productivity could be quite high, about 10 or even 100 times more productive than traditional bioenergy feedstocks (USDOE 2014). Current algae production for fuels is very small as there are only field trials by private and public entities to test the technological and economic viability of this resource. Under current technology, algae have the future potential to generate 58 billion gallons of oil per year, equivalent to 48% of the current U.S. petroleum imports for transportation (Milbrandt et al. 2013). Algae are estimated to be most productive in the southern states, especially Texas and Florida (Wigmosta et al. 2011).

Biomethane refers to the methane component of biogas. Biogas is the gaseous product of the decomposition of organic matter, usually comprised of 50% to 80% methane and 20% to 50% carbon dioxide by volume with traces of gases such as hydrogen, carbon monoxide, and nitrogen. The methane content of biogas is the usable portion of the gas and determines its calorific value[23]. The methane potential from landfill material, manure, wastewater, and industrial, institutional, and commercial organic waste in the United States is estimated at about 9 million tons per year, which is equal to about 420 billion cubic feet or 431 trillion Btu (NREL

[23] Other gases are less usable with current systems.

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2013). This amount could displace about 5% of natural gas consumption in the electric power sector, or 56% of natural gas consumption in the transportation sector.

2.6 Feedstock Outlook

The overall trends for biomass feedstock production have been relatively flat over the past decade. However, the commercialization of biomass feedstocks is occurring, and the trajectory of feedstock utilization is happening, as expected, with waste and residue resources being commercialized first. Forward-looking and projected biomass availability data is available in the *U.S. Billion-Ton Update* (USDOE 2011). For reference, Appendix A provides a comparison of some of the feedstock data presented in the *U.S. Billion-Ton Update* with data presented in this market report. While projections for future growth vary across a broad range, reaching higher levels of production would require various technological and market advancements, for example, higher crop yields or commercialization of additional feedstock, such as dedicated energy crops and algae. There has been and will continue to be competition for biomass feedstock not only within the bioenergy technologies industry (biofuels and biopower) but with other industries as well (fiber, feed, and chemical products). The future availability of biomass resources for bioenergy will depend on many factors, such as local market demand, rate of bioenergy technologies commercialization, the development of drought-tolerant strains, and feedstock selling price. The development and availability of these resources for bioenergy also will be driven by oil prices, climate change, and renewable energy policy actions, as well as energy security concerns.

3 Biofuels Markets

As evidenced in Figure 10, conventional ethanol dominates total biofuels production, followed by biodiesel with total biofuels production of 14.6 billion gallons in 2013. Small quantities of advanced biofuels began to enter commercial markets in 2012 and 2013.

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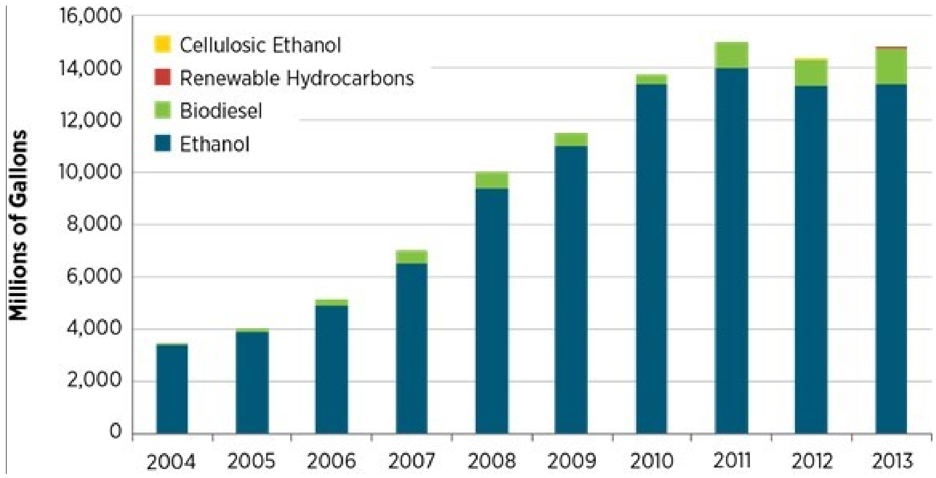

2012: cellulosic ethanol: 20,069 gallons, renewable hydrocarbons: 1,024 gallons; 2013: cellulosic ethanol: 0 gallons, renewable hydrocarbons: 514,627 gallons.

Figure 10. U.S. renewable fuels production

Sources: Ethanol and Biodiesel Production: EIA Annual Energy Review, Tables 10.3, 10.4, http://www.eia.gov/totalenergy/data/annual/index.cfm; Cellulosic Ethanol and Renewable Hydrocarbons: EPA-RFS2 2013.

The primary market driver for advanced biofuels production and consumption is the RFS. The RFS originated with the Energy Policy Act of 2005 and was expanded and extended by the Energy Independence and Security Act of 2007 (EISA). The RFS program requires renewable fuel to be blended into transportation fuel in increasing amounts each year, escalating to 36 billion gallons by 2022. There are two overall RFS categories: (1) conventional, which is largely satisfied by corn ethanol and (2) advanced, which includes biodiesel and fuels made from cellulosic or other advanced feedstocks. Each renewable fuel category in the RFS program must emit lower levels of greenhouse gases relative to the petroleum fuel it replaces. Specific greenhouse gas emission reductions are 20% for renewable fuel (conventional category)[24]; 50% for biodiesel; 60% for biofuels from cellulosic feedstocks; and 50% for biofuels from other advanced feedstocks.

In order to meet the fuel blend requirements, the RFS program assigns obligated parties (fuel refiners, blenders, and importers) a renewable volume obligation (RVO), which is the volume of renewable fuels the party is obligated to blend based on a percentage of the company's total fuel sales. The U.S. Environmental Protection Agency (EPA) manages and tracks RFS compliance through Renewable Identification Numbers (RINs). RINs are the mechanism for tracking annual renewable fuel blend requirements across the various biofuel categories. RINs are generated when designated biofuels are imported or produced and conveyed with the volumetric sale of those biofuels until blended with petroleum products or sold in another compliant form. Once the fuel is blended, the RIN can be used to demonstrate a company's RVO compliance to the EPA and then retired. RINs also may be sold or saved for meeting RVO compliance in the next

[24] Facilities that existed or commenced construction prior to December 19, 2007, are exempt from the 20% life-cycle GHG threshold requirement; ethanol plants that began construction prior to January 1, 2010, and use natural gas or biomass for thermal energy are also exempt.

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compliance year. RIN prices are determined by market factors typical of other commodities (EPA-RFS 2014).

3.1 Ethanol

Ethanol is a widely used renewable fuel made from corn and other plant materials. It has a long history of use in the United States dating back to the introduction of motor vehicles. It became more common as an oxygenate additive and octane enhancer in gasoline after passage of major amendments to the Clean Air Act in 1990 required oxygenates be used in reformulated gasoline. Production and use grew dramatically to meet these standards. However, another oxygenate, methyl tertiary-butyl ether (MTBE), was the primary product used to meet the standard until it was found to contaminate ground water, and some states banned the use or proposed banning its use. Ethanol was then used to replace MTBE in these areas and production and consumption increased dramatically. Today, ethanol consumption is driven by both the RFS and octane requirements. As of late 2013, pipelines shipped a variety of gasoline and gasoline blend stocks to meet customer requirements, which vary regionally. Many of these products are sub-octane, meaning they have a lower octane than is required for sale to consumers at the pump. Ethanol has a higher octane number than gasoline and refiners provide a gasoline blend stock that when blended with ethanol will meet octane specifications necessary to meet the vehicle performance needs. Ethanol is delivered to terminals or blenders by rail car, tanker truck, or barges and blended with gasoline for delivery to end users.

In 2013, 98% of domestic ethanol production was from corn. Advancements have been made to utilize cellulosic feedstocks (RFA 2014a). Current market conditions indicate that the motor vehicle fuel market would need to expand or transition to accommodate additional volumes of ethanol from cellulosic feedstocks because the cellulosic RFS requirement alone may not be enough to encourage investors to produce cellulosic ethanol.

The benefits of ethanol include a higher octane number than gasoline, which provides increased engine power and performance. As a domestically produced renewable fuel, ethanol reduces reliance on petroleum products and foreign imports and provides jobs in rural areas. In 2005, 60% of petroleum products were imported; however, that was reduced to 35% in 2013 as a result of increased domestic crude oil and ethanol production (imports would have been 41% without ethanol) (RFA 2014a). Greenhouse gas emissions are reduced on average by 34% with corn ethanol, and up to 108% if cellulosic feedstocks are used, compared with gasoline production and use (Wang et al. 2012).

More than 96% of gasoline sold in the United States contains ethanol and nearly all ethanol is sold as E10 (10% ethanol, 90% gasoline) (RFA 2014b). Another long-available blend is E85—containing 51% to 83% ethanol, depending on geography and season—for use in flexible fuel vehicles (FFV). At the end of 2013, E85 was available at more than 2,600 fueling stations and 16.8 million FFVs were registered nationwide. In 2011, the EPA approved E15 (15% ethanol, 85% gasoline) for use in model year (MY) 2001 and newer vehicles. Although the number of stations offering E15 grew from 12 in January 2013 to 70 at the start of 2014 (RFA 2014a)[25],

[25] Renewable Fuels Association has provided E15 station numbers to NREL on several occasions.

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retailers have been slow to sell this fuel citing liability concerns, particularly for misfueling (NACS 2013).

The primary drivers of ethanol prices are the cost of corn and the gasoline prices for which ethanol serves as a substitute product. In the past 10 years, ethanol prices have fluctuated in correlation with gasoline or corn prices. When corn was relatively inexpensive and petroleum prices were increasing (from 2004 through 2010), ethanol futures traded on the basis of gasoline prices. As ethanol began to consume a larger percentage of corn production, its price increasingly moved in sync with corn prices when domestic supply of corn was tight. More recently, as corn prices have dropped lower, ethanol prices have been based on a discount from gasoline prices. Figure 11 compares ethanol and gasoline futures prices. The correlation between corn and ethanol prices is expected to decline once substantial volumes are produced from cellulosic feedstock.

Figure 11. Historic ethanol futures prices

Sources: Ethanol: CME Group ethanol future prices collected by Agricultural Marketing Resource Center. March 7, 2014; Gasoline: EIA Petroleum & Other Liquids NYMEX Futures Prices.

3.1.1 Conventional Ethanol

Conventional ethanol dominates the current ethanol market, and in nearly all cases it is made from corn (98%) with a few mills using milo (grain sorghum) or food/beverage wastes (RFA 2014a). This fuel meets the overall renewable fuel category of the RFS.

The majority of ethanol is produced using dry mill technology (90%); a small number of larger plants use a wet milling process (10%) (RFA 2014a). Dry-milling is a process that grinds corn into flour and ferments only the starch component into ethanol with co-products of distillers grains and carbon dioxide. Wet-mill plants primarily produce corn sweeteners, along with ethanol and several other co-products (such as corn oil and starch). Wet mills separate starch, protein, and fiber in corn prior to processing these components into ethanol and other products.

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3.1.1.1 Historical Production, Consumption, and Capacity

Figure 12 highlights the tremendous growth in capacity, production, and consumption of ethanol since 2000. The past few years saw production plateau due to the blend wall. Figure 13 illustrates the rapid build out of plants and capacity over the past decade. The number of plants operating at any given time is a function of economics and demand and plants may idle at different times during the year depending on ethanol and corn prices[26]. Installed capacity is capable of meeting the overall RFS renewable fuel category of 15 billion gallons. As of January 2014, there were 210 fuel ethanol plants in 28 states with installed capacity of 14.9 billion gallons producing 13.3 billion gallons (Figure 14). Plant ownership is not consolidated—there are more than 120 ownership organizations, but there are four companies that own 27% of plants and 37% of installed capacity: POET (27 plants; 1.8 billion gallons), ADM (8 plants; 1.7 billion gallons), Valero (10 plants; 1.1 billion gallons), and Green Plains Renewable Energy (12 plants; 1.0 billion gallons). Only nine ownership groups are traded publicly and they account for 20% of plants and 35% of installed capacity (RFA 2014b)[27].

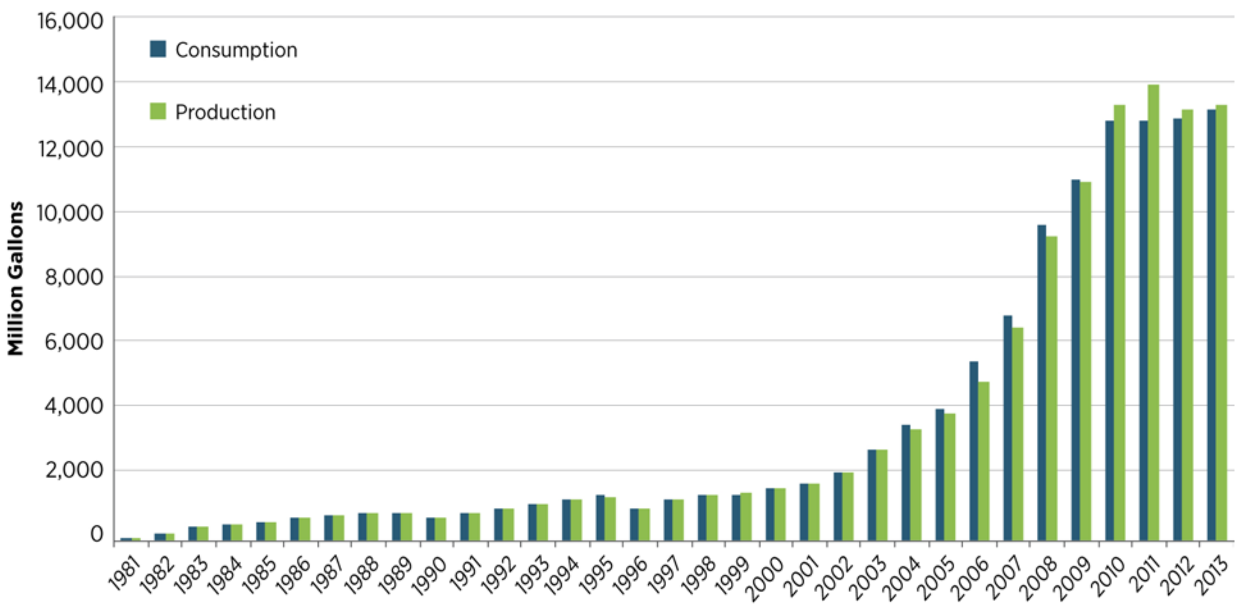

Figure 12. U.S. historical ethanol production and consumption

Source: EIA Annual Energy Review, Table 10.3: http://www.eia.gov/totalenergy/data/annual/index.cfm.

[26] Renewable Fuels Association maintains a continuously updated list of installed and operating ethanol plants: http://www.ethanolrfa.org/resources/biorefinery-locations.

[27] Public ethanol plants ownership companies include: Abengoa, ADM, Aventine Renewable Energy Holdings, Green Plains Renewable Energy, GTL Resources, Pacific Ethanol, Renova Energy, The Andersons Inc., and Valero.

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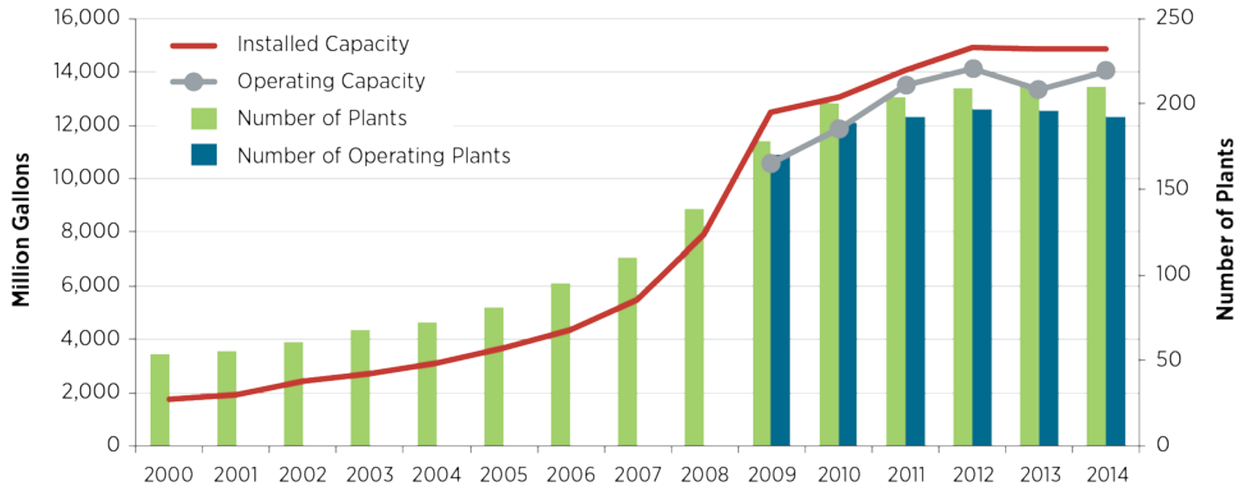

Figure 13. U.S. historical ethanol plants

Source: RFA Ethanol Industry Outlooks 2000-2014: http://www.ethanolrfa.org/resources/publications/outlook.

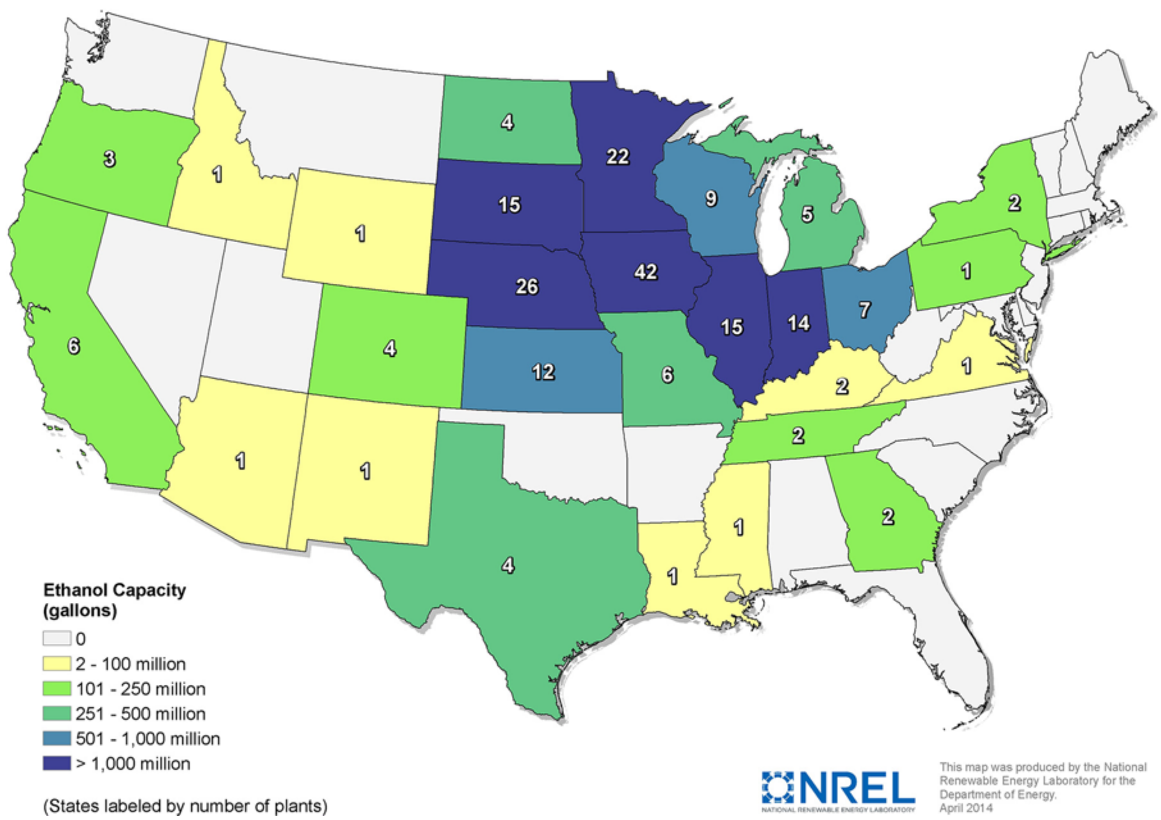

Figure 14. Starch ethanol plants by state (as of January 2014)

Source: "Falling Walls & Rising Tides." 2014 Ethanol Industry Outlook. Renewable Fuels Association. February 2014.

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3.1.1.2 Production Cost

Because of the scarcity of data on the actual production cost of corn ethanol, economic models were developed to estimate production cost and track ethanol profitability. A model created by Iowa State University (ISU) can be used to estimate the production cost for a typical northern Iowa natural-gas-fired ethanol plant with an annual capacity of 100 million gallons (Hofstrand 2014a). The plant represents similar facilities built around 2007 in Iowa, but may not be representative of plants in other regions (Hofstrand 2014a). The estimated production cost, as shown in Figure 15, takes into account fixed costs, non-feedstock variable costs (e.g., natural gas, chemicals, and labor), feedstock costs, and revenue contribution from co-product(s) (dry distillers grains assumed by the model), and varied from less than $1.50/gallon to about $3.50/gallon in the past several years (Hofstrand 2014a).

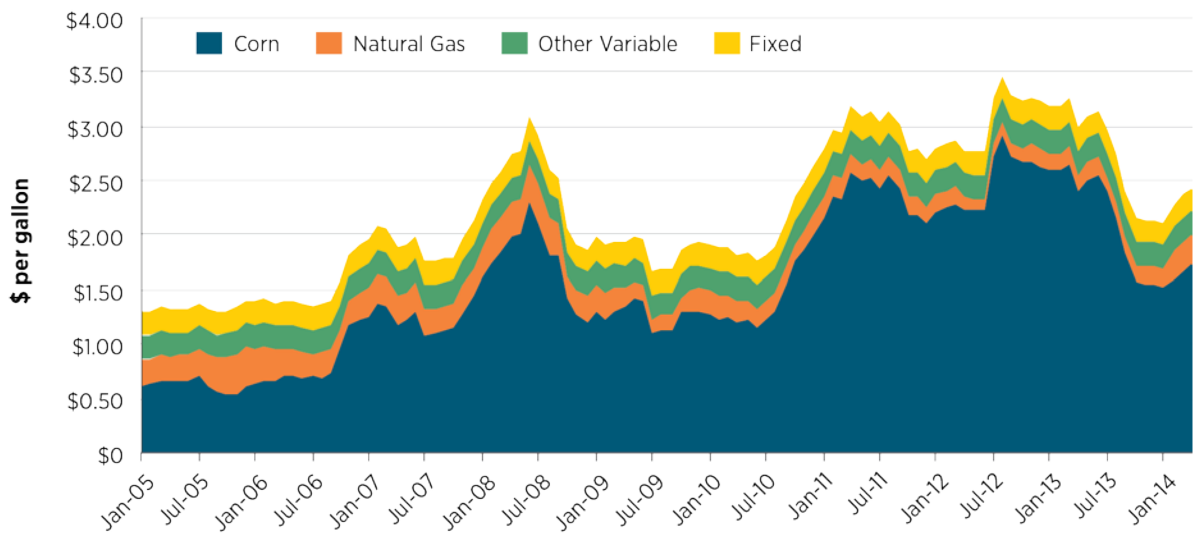

Figure 15. U.S. corn ethanol production cost trends

Source: Hofstrand, D. Ag Decision Maker, D1-10 Ethanol Profitability. Agricultural Marketing Resource Center, Iowa State University.

The single largest cost in the production of ethanol from corn is the cost of corn (Figure 15). Corn prices vary from year to year and have ranged from $1.50/bushel to $6.90/bushel in the last three decades (from 1983–2013) (USDA-ERS 2014a)[28]. Corn prices also vary based on the proximity to export markets resulting in states like North Dakota, South Dakota, Minnesota, and Nebraska, typically having the lowest corn prices due to the cost of shipping corn to export locations. Similarly, corn ethanol plants in those states usually have the lowest ethanol production costs in the nation. Another major production cost contributor is the price of natural gas or other sources of heat needed for the conversion process. The market price of ethanol does not necessarily reflect the cost of ethanol production.

The largest ethanol markets are located on the East and West Coasts of the United States, outside of the primary corn production region. The majority of ethanol produced in the United States is shipped on trains to those markets. While these costs are minimal they are increasing as ethanol

[28] 1 bushel of corn=56 pounds and 1 bushel of corn yields approximately 2.8 gallons of ethanol.

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competes with newly discovered domestic oil fields and copes with anticipated new safety standards for tank cars. Ethanol prices are typically lowest in the Midwest and increase as a function of transport costs when shipped to other domestic markets.

3.1.1.3 Co-Product Overview

Fuel ethanol co-products from dry mills include distillers grains, corn oil, and carbon dioxide. Corn is approximately 2/3 starch, which is converted into ethanol and carbon dioxide; the remaining 1/3 is protein and fat that is converted into distillers grains. Distillers grains are the highest volume co-product and are sold as livestock feed either wet (46 pounds/bushel at 65% moisture) or dry (18 pounds/bushel at 10% moisture). Approximately 80% of ethanol plants have added dry fractionation technology at the front end of their plant to extract non-edible corn oil at a rate of about 0.5 pounds/bushel, which is most often used as a feedstock for biodiesel plants (Jessen 2013a)[29]. Only 36 ethanol plants sell carbon dioxide (6.6 pounds/gallon of ethanol) to industry for use in food and pharmaceutical products, and prices for raw carbon dioxide gas range from $5–$25/ton (Rushing 2011). More plants would likely sell carbon dioxide if they were near the end user; most ethanol plants are located in rural areas.

Benchmarking studies have found that the co-product contribution to revenues has increased in recent years—largely due to corn oil—going from an average of 16.5% of revenue contribution in 2008 to 23% in the first half of 2012 (Jessen 2013b). Pricing for distillers grains and corn oil is a function of corn price and driven by demand by the markets they serve. Distillers grains export markets have grown over time to supplement corn exports (Figure 16). Production data for corn oil is unknown and may vary with the extraction rates of various technologies. USDA reports a market year 2012/13 inedible corn oil price of 36.77 cents/pound (USDA-ERS 2014b).

[29] Corn oil extraction rates range from 0.4 to 0.9 pounds per bushel (Jessen 2013b); however, many ethanol plants do not go for higher extraction rates since distillers grains customers expect a certain oil content.

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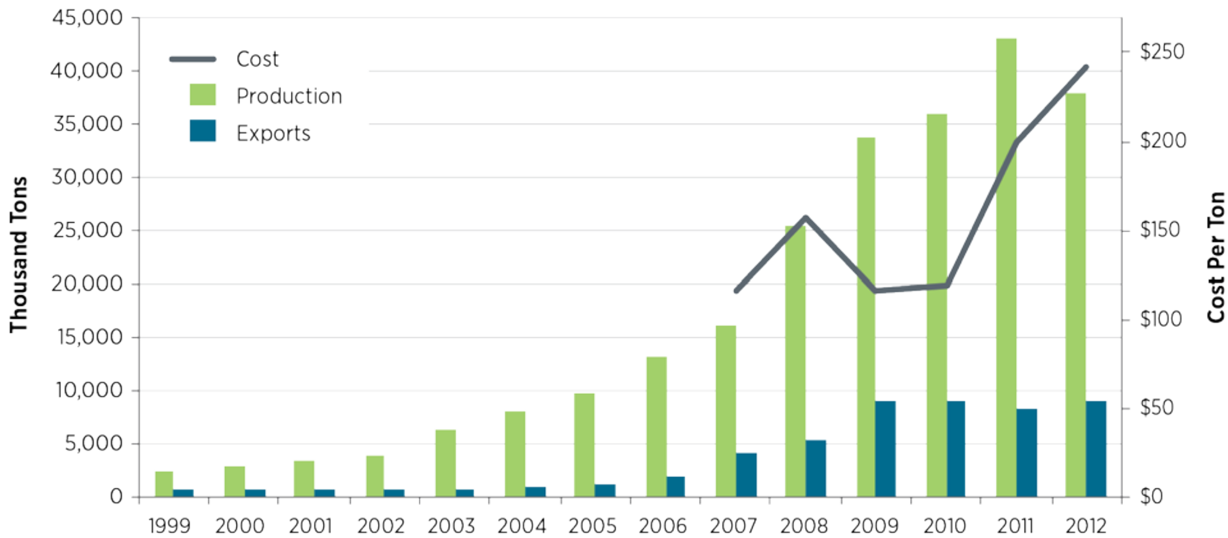

Figure 16. U.S. starch ethanol distillers grains production, trade, and price

Sources: Production: Historic Distillers Grains Production from U.S. Ethanol Biorefineries, Renewable Fuels Association Industry Resources; Exports: USDA Feed Grains Yearbook Table 34; Cost: Ethanol, Corn, and DDG Prices at Production Facilities (annual average of prices at production facilities in Iowa, Illinois, Nebraska, South Dakota, and Wisconsin), USDA Agricultural Marketing Resource Center.

3.1.1.4 Economic Impacts of Conventional Ethanol

The economic impact of corn ethanol expansion is significant, in particular among the states where ethanol plants are located and corn production increases partially as a result of rising demand for ethanol production. Processing raw corn into ethanol adds value to the feedstock through activities that support the necessary investment in processing, marketing, construction, and research and development (R&D). These value-adding activities not only benefit local and regional production, but also generate additional economic activities through spending that is directly and indirectly induced by payments to workers and returns to investors.

Annually, the ethanol industry funded studies to determine the impacts of ethanol production on the economy (Urbanchuk 2006; Urbanchuk 2014). These studies applied a commonly used economic input-output model known as IMPLAN to estimate value added (total value of the goods and services produced by businesses), income, and employment resulting from the corn ethanol industry each year.

- Ethanol contribution to gross domestic product (GDP) increased from $17.7 billion annually in 2005 to $44 billion in 2013.
- The number of direct jobs has remained somewhat level with 87,883 during the rapid build out of plants in 2005 and 86,503 in 2013.
- The contribution of tax revenue grew from $1.9 billion in 2005 to $8.3 billion in 2013.
- The contribution to household income increased from $14.6 billion in 2005 to $30.7 billion in 2013.

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3.1.2 Cellulosic Ethanol Production

As the corn ethanol industry has matured, interest has moved toward using non-food cellulosic feedstocks such as crop residues, waste wood, MSW, and dedicated energy crops to produce ethanol. Ethanol made from cellulosic feedstock meets the same ASTM International fuel quality standards as conventional ethanol and has the same performance in vehicles. After decades of technology development, the cellulosic ethanol industry is now reaching commercial production. Commercial deployment of cellulosic biofuels has been hampered by the economic downturn as financial investment was constricted, particularly due to the high startup risks for these new technologies. These risks include feedstock availability, feedstock collection, and delivery; pre-treatment technology costs; higher capital costs; and technology scale-up challenges.

Cellulosic ethanol is produced via biochemical, thermochemical, and hybrid technology pathways. In the biochemical pathway, cellulose and hemicellulose in the feedstock is deconstructed into simple sugars through various pretreatment processes and enzymes. Microbes are used to ferment the sugars into ethanol and other alcohols. The thermochemical pathway uses heat to transform the feedstock into a syngas comprised of hydrogen and carbon monoxide that is catalytically converted to ethanol and other alcohols and compounds. Hybrid technologies use a combination of biochemical and thermochemical operations—for example, syngas fermentation thermochemically deconstructs the feedstock into syngas, which microbes ferment into fuel or bioproducts.

Despite challenges in technology development, investment constraints from the recession, and market conditions for ethanol, the industry is seeing the first commercial-scale cellulosic ethanol plants being built. The EPA reports small volumes of cellulosic ethanol production with about 20,000 gallons in 2012, none in 2013, and nearly 28,000 in the first quarter of 2014 (EPA 2014).

3.1.2.1 Commercialization of Cellulosic Ethanol

A study of U.S. non-starch ethanol producers was conducted to understand the status of the cellulosic ethanol industry at the end of calendar year 2013 (Schwab et al. 2015). No U.S. facilities produced cellulosic ethanol during 2013 that resulted in the assignment of a RIN (EPA-RFS2 2013). Table 3 summarizes the U.S. commercial cellulosic ethanol capacity identified during the 2013 study. Four of the commercial facilities identified in this study were scheduled to become operational sometime after the end of 2013. These anticipated operational start dates represent forward-looking projections from the study, which will be updated in future studies after these facilities become operation. As shown in Table 3, the INEOS facility entered service in 2012; however, it did not produce any cellulosic ethanol that resulted in RINs during 2013. For the purposes of the 2013 study, this INEOS facility was classified as still under construction during 2013, as the facility underwent modifications and upgrades (INEOS 2013).

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Table 3. Status of U.S. Commercial-Scale Cellulosic Ethanol Capacity at the End of 2013

Company	Project Location	Technology Pathway	Feedstock Category	Capacity [MMGY]	Operational Year (Anticipated)
Abengoa	Hugoton, KS	Biochemical	Crop Residues	24	(2014)
Beta Renewables, Inc.	Clinton, NC	Biochemical	Dedicated Energy Crops	20	(2016)
DuPont	Nevada, IA	Biochemical	Crop Residues	30	(2014)
INEOS New Planet Bioenergy LLC	Vero Beach, FL	Thermochemical Gasification	Vegetative and Yard Wastes	8	2012
POET Design & Construction	Emmetsburg, IA	Biochemical	Crop Residues	22.5	(2014)

Source: Schwab et al. 2015.

Figure 17 presents a summary of all the non-starch ethanol facilities included in the 2013 study. Nine of the 25 non-starch ethanol facilities included in this report were under construction at the end of 2013, with the remainder of the facilities spread across the other stages of development. It was observed that five of the facilities (three pilot-scale facilities and two demonstration-scale facilities) were reported as idle at the end of 2013. Insufficient information was gathered during the study to determine why these particular facilities were idle at the end of 2013. However, as a natural part of the development process, smaller scale facilities may eventually become idle (or be repurposed) as the project matures, a facility has served its purpose, and larger scale facilities are built.

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Scale of Facility	Company Name_Facility Location	Planning	Under Construction	Operating	Idle
Commercial	Abengoa_KS		+ (green)		
	Beta Renewables_NC		× (green)		
	BlueFire Renewables, Inc._MS	△ (green)			
	Canergy, LLC_CA	× (green)			
	DuPont_IA		+ (green)		
	Fiberight_IA	◇ (green)			
	INEOS New Planet BioEnergy LLC_FL		◇ (red)		
	Mascoma_MI	△ (green)			
	POET Design & Construction_IA		+ (green)		
Demonstration	American Process Inc_MI		△ (green)		
	BP_LA			× (green)	
	Coskata_PA				△ (red)
	DuPont_TN			+ (green)	
	Lignol Innovations_Undisclosed	△ (green)			
	Mascoma_NY				△ (green)
	RSA d/b/a Old Town Fuel & Fiber_ME	△ (green)			
	ZeaChem_OR			△ (green)	
Pilot	Algenol Biofuels Inc._FL		□ (orange)		
	Archer Daniels Midland_IL		+ (purple)		
	Arkenol_CA				△ (green)
	Fiberight_VA				◇ (green)
	ICM, Inc._MO			* (green)	
	LanzaTech_GA		△ (red)		
	Logos Technologies_CA				+ (green)
	POET Design & Construction_SD			○ (green)	

Technology Pathway
- Algae Tech (orange)
- Biochemical (green)
- Hybrid BC/TC (purple)
- Thermochemical Gasification (red)

Feedstock Category
- ○ Not Reported
- □ Algae
- + Crop Residues
- × Dedicated Energy Crops
- * Herbaceous Mix
- ◇ Vegetative and Yard Waste
- △ Woody Biomass

Figure 17. Characteristics of U.S. non-starch ethanol facilities at the end of 2013

Source: Schwab et al. 2015.

Most of the cellulosic ethanol facilities—20 of 25—use or will use a biochemical technology pathway, with three using a thermochemical gasification route, one using a hybrid biochemical/thermochemical technology, and one using an algal technology pathway for the direct production of ethanol. During this study, each facility self-identified the conversion technology pathway that best describes their particular facility. Since companies typically employ a proprietary conversion process, there may be aspects of a company's process that incorporate elements of technology pathways other than the primary technology pathway indicated in Figure 17.

The 20 facilities using a biochemical technology pathway used a range of feedstock materials. Of the 20 biochemical pathway facilities, eight facilities were using woody biomass, five were using crop residues, three were using dedicated energy crops, two were using vegetative and yard

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waste, one was using an herbaceous mix, and one facility did not report a specific feedstock. The three thermochemical gasification facilities used either woody biomass (two facilities) or vegetative and yard waste (one facility) as feedstock. The one facility using a hybrid biochemical/thermochemical pathway utilized crop residues as feedstock.

3.1.2.2 Production Costs and Economic Impacts

Figure 18 illustrates how significant technology developments over the last few decades are enabling cost-competitive cellulosic ethanol to come to commercial-scale production. In 2012, researchers at the National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), and Idaho National Laboratory (INL), funded through the U.S. Department of Energy (DOE), successfully demonstrated—at significant scale—two cellulosic ethanol production processes at a projected mature commercial-scale cost of $2.15 per gallon (2007$) from corn stover and $2.05 per gallon (2007$) from woody feedstocks (Tao et al. 2014; Dutta et al. 2014). Based on the assumptions in these design case reports, calculated costs included feedstock harvesting, transportation, and integrated conversion. The costs were reached through modeling and integrated pilot-scale validation and met the goals set by the DOE's Advanced Energy Initiative of 2006 to show that cellulosic ethanol could be cost competitive with corn ethanol and conventional fuels. Continued research may further decrease production costs. For example, in 2013, a partnership between INL and ISU achieved critical corn stover feedstock processing targets that enable cost-competitive biofuels and identified best practices for replication with a variety of herbaceous feedstocks. DOE-funded industry research also has resulted in commercially viable strains of yeast and bacteria, and enzymes. These and other such improvements are expected to be implemented in newly constructed cellulosic ethanol biorefineries.

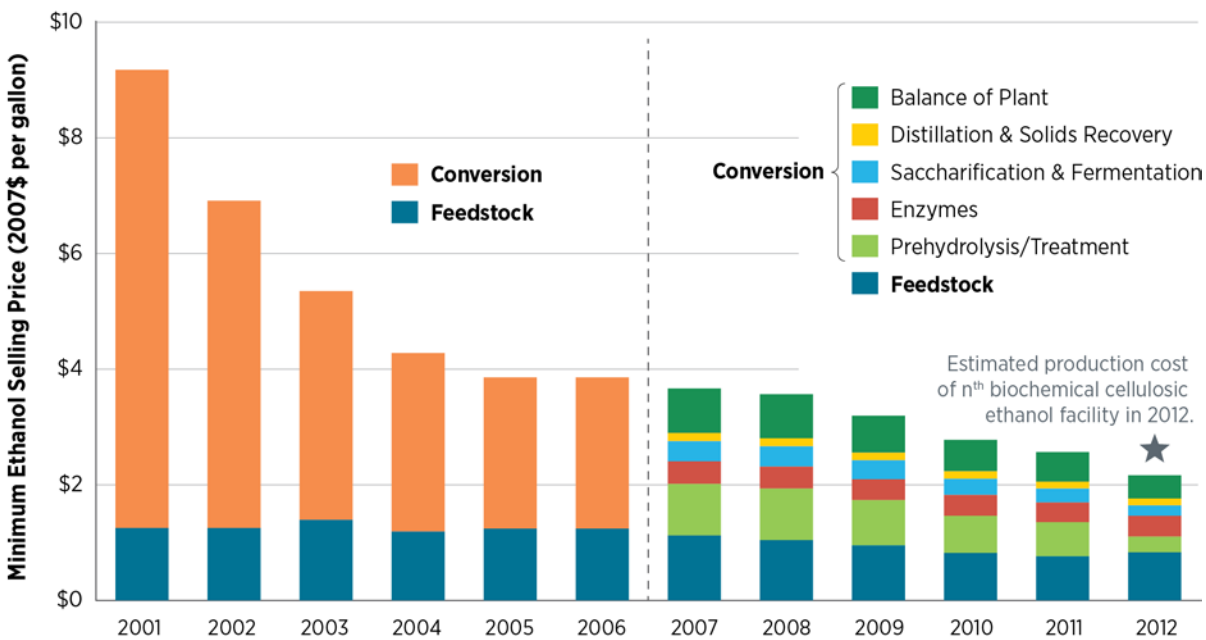

Figure 18. Biochemical cellulosic ethanol modeled production costs over time

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Techno-economic analyses suggest that cellulosic ethanol facilities with a capacity of about 60 million gallons/year are expected to hire approximately 60 on-site workers (Dutta et al. 2011; Humbird et al. 2011). Labor requirements will depend on which conversion process is employed, system configuration, size of the facility, and other factors such as the feedstock type and handling. Cellulosic ethanol also will result in jobs for those gathering and delivering feedstock and other inputs and equipment to the plant.

3.1.2.3 Co-Products Overview

In current process designs for the biological conversion of cellulose- and hemicellulose-derived sugars to ethanol, lignin is burned to generate process heat and electricity, with any excess power produced being sold as a co-product. The exported electricity improves the profitability of the process and has a positive impact on sustainability by displacing fossil-derived electricity and reducing greenhouse gas emissions (Wyman 2003; Humbird et al. 2011). For example, INEOS is expected to produce 6 MW of renewable biomass power per year in addition to producing 8 million gallons per year of cellulosic ethanol. As highlighted in a recent review article on lignin valorization, there are extensive opportunities for further improvements in the overall economics and sustainability of a biorefinery complex via utilization of all of the components of biomass (Ragauskas et al. 2014). This potential improvement on the overall economics and sustainability for an integrated biorefinery was investigated in the NREL design report (Davis et al. 2013) focused on the biological conversion of cellulosic sugars to hydrocarbon fuels. In this study, the conversion of lignin to products including 1,4-butanediol and adipic acid resulted in improving the overall process economics, as well as potentially reducing the greenhouse gas emissions relative to the production of electricity from lignin (Davis et al. 2013). Continued research and development in catalysis and improvements in process integration may address the challenges and barriers for the conversion of lignin to fuels and chemicals.

3.1.3 Policies that Affect the Ethanol Market

Ethanol received significant government support under federal law in the form of mandated fuel use, tax incentives, loan and grant programs, and other regulatory requirements[30]. The ethanol market has expanded due to both regulation and market factors. Federal regulations that have influenced the market include a series of federal (and state) tax incentives, the Energy Policy Act of 1978, which helped grow what was a small start-up industry; the RFS in the Energy Policy Act of 2005, which mandated blending 7.5 billion gallons of renewable fuel with gasoline annually by 2012; and EISA in 2007, which expanded the RFS to 36 billion gallons by 2022. Another significant market driver was the replacement of MTBE with ethanol—specifically E10. MTBE was previously used to increase octane but concerns about groundwater contamination caused some states to ban its use in 2005 and 2006, leading to its discontinued use; it was replaced with E10. A sustained period of high gasoline prices and low corn prices led to a rapid expansion of ethanol production capacity (Tyner 2008). The federal incentives were provided in the form of a motor fuel excise tax exemption or a tax credit along with additional tax credit for small ethanol producers. In addition, a tariff on imported ethanol gave domestic producers a competitive advantage over foreign producers (Pelkmans et al. 2008).

[30] This section covers federal incentives and policies. States also may have incentives and policies. This information is available from the Alternative Fuels Data Center Laws and Incentives website: http://www.afdc.energy.gov/laws.

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A number of federal incentives for ethanol producers and blenders expired at the end of 2011, including the volumetric ethanol excise tax credit (VEETC)—considered the largest renewable-related tax incentive—small ethanol producer tax credit, and import tariff for fuel ethanol. Initially, the federal government subsidized ethanol by exempting ethanol gasoline blends from excise taxes and establishing a tax credit for ethanol use in the late 1970s. In 2004, the American Jobs Creation Act implemented the VEETC to replace the two historical subsidies as a combined excise tax exemption and tax credit (Taxpayers for Commonsense 2011). The tax credit was paid to ethanol blenders (petroleum companies) rather than ethanol plants, though the ethanol price was certainly impacted by the tax credit. The value of the tax credit was $0.51/gallon from 2004 through 2008 and $0.45/gallon between 2009 and 2011 (Kim et al. 2010). The VEETC was discontinued at the end of 2011 with the support of the ethanol industry because conventional ethanol had reached commercial maturity and the incentive was no longer necessary. Table 4 shows the historical VEETC federal support to corn ethanol based on production and VEETC payment per gallon.

Table 4. Historical VEETC Federal Investment

Year	VEETC (billion$)
2004	1.7
2005	2.0
2006	2.5
2007	3.3
2008	4.7
2009	4.9
2010	6.0
2011	6.3

Calculated by multiplying ethanol production by tax incentive ($0.51/gallon for 2004–2008 and $0.45/gallon for 2009–2011).

Source: EIA Annual Energy Review, Table 10.3: http://www.eia.gov/totalenergy/data/annual/index.cfm.

Cellulosic ethanol also has received significant government support under federal law in the form of biomass grower payments, mandated fuel use, tax incentives, loan and grant programs, and other regulatory requirements. The most significant incentive for cellulosic ethanol production has been the RFS. Cellulosic ethanol is considered an advanced biofuel under the RFS. However, given the industry's slow startup, production has been lower than originally projected, resulting in yearly reductions by the EPA of the cellulosic RVO. Other policy supports include grants through the DOE's Bioenergy Technologies Office (BETO) for first-of-a-kind biorefineries using biomass feedstocks[31], as well as payments to biomass feedstock growers under the USDA Biomass Crop Assistance Program (BCAP). Loan guarantees also are available for cellulosic ethanol plants through the DOE and USDA. A cellulosic biofuel production tax

[31] For more information on integrated biorefinery projects visit: http://www.energy.gov/eere/bioenergy/integrated-biorefineries.

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credit of $1.01/gallon expired at the end of 2013, and was extended retroactively through the end of 2014 when it once again expired. While the industry has received financial support in recent years, currently there are fewer federal incentives for demonstration and deployment of cellulosic and algal biofuels.

3.1.4 Ethanol Trade

Ethanol is both imported and exported as a function of demand or renewable fuel use requirements in other nations (Figure 19). The United States is the world leader in ethanol production, accounting for 60% of 2013 world production (RFA 2014a). In 2013, imports were from six countries with nearly 80% of the total 306 million gallons coming from Brazil and the balance coming from Costa Rica, El Salvador, France, and Canada (EIA 2014c). Sugarcane ethanol qualifies as an advanced biofuel in the RFS and also meets California's low carbon fuel standard leading to bidirectional trade. The United States exported 622 million gallons in 2013 to 51 nations with the majority going to Canada (52%), Philippines (9%), and Brazil (8%) (EIA 2014c). There were few exports to European Union member nations due to an import tariff on U.S. ethanol.

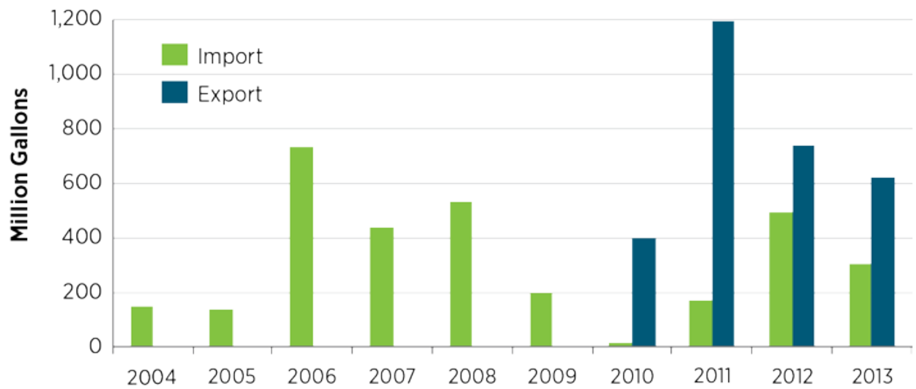

Figure 19. U.S. ethanol imports and exports

Source: EIA 2014c.

3.1.5 Infrastructure

Infrastructure is a critical part of the supply chain in deploying alternative transportation fuels. Significant research and outreach activities have resulted in blends above E10 being used in both specifically designed equipment and existing refueling equipment. Regulations have long accommodated the use of E10 in existing infrastructure. Blends above E10 require specialized equipment to meet the patchwork of regulations that cover refueling infrastructure. Codes and standards for refueling agencies are developed and enforced by many organizations, including the EPA's Office of Underground Storage Tanks (OUST), authorities having jurisdiction (AHJ—typically fire marshals), Underwriters Laboratories (UL), the Occupational Safety and Health Administration (OSHA), fire safety code organizations, and many other industry groups.

OUST is responsible for federal codes for fuel storage and it issued an alternative compliance method in 2011 to address storing biofuel blends above E10 or B20 (20% biodiesel, 80%

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petroleum diesel) in existing tanks (EPA 2011). While a majority of installed tanks and pipes are compatible with ethanol blends up to E85 or E100[32], UL-listed equipment for blends above E10 became available in 2010; however, many stations sold E85 prior to the availability of this equipment and those stations likely received a waiver from their AHJ. More recently, DOE, UL, and manufacturers worked together to develop a method to allow sales of E15 in existing dispensers resulting in UL-listed retrofit kits—a low-cost solution that allows sales of up to E25 in existing dispensers. Stations interested in selling ethanol blends can refer to Clean Cities' *Handbook for Handling, Storing, and Dispensing E85 and Other Ethanol-Gasoline Blends,* which explains all steps and regulations and provides lists of compatible and UL-listed equipment[32].

E85 is available at 2,683 stations in 47 states (Figure 20 and Figure 21); however, there are often low densities of E85 stations in areas with high concentrations of capable vehicles (AFDC 2014)[33]. It is possible that E85 sales could increase if more E85 stations were located in areas with high concentrations of FFVs but only when the price is discounted to reflect the lower energy density of ethanol compared with gasoline. Approximately 350 of the E85 stations offer multiple ethanol blends to FFV drivers through blender pumps. As of April 2014, there were 75 stations in 12 states selling E15[34].

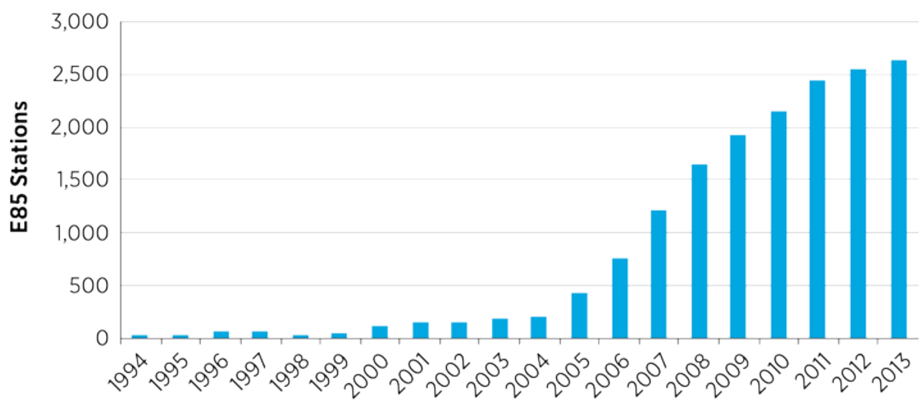

Figure 20. U.S. historical E85 stations

Source: Alternative Fuels Data Center: http://www.afdc.energy.gov/fuels/stations_counts.html.

[32] Clean Cities' *Handbook for Handling, Storing, and Dispensing E85 and Other Ethanol-Gasoline Blends* provides lists of compatible tanks, pipes, and associated underground storage tank equipment, as well as UL-listed dispensers and hanging hardware: http://www.afdc.energy.gov/uploads/publication/ethanol_handbook.pdf.
[33] TransAtlas shows locations of both alternative fuel stations and vehicles: http://maps.nrel.gov/transatlas.
[34] Renewable Fuels Association tracks E15 stations and provided the station count for this report.

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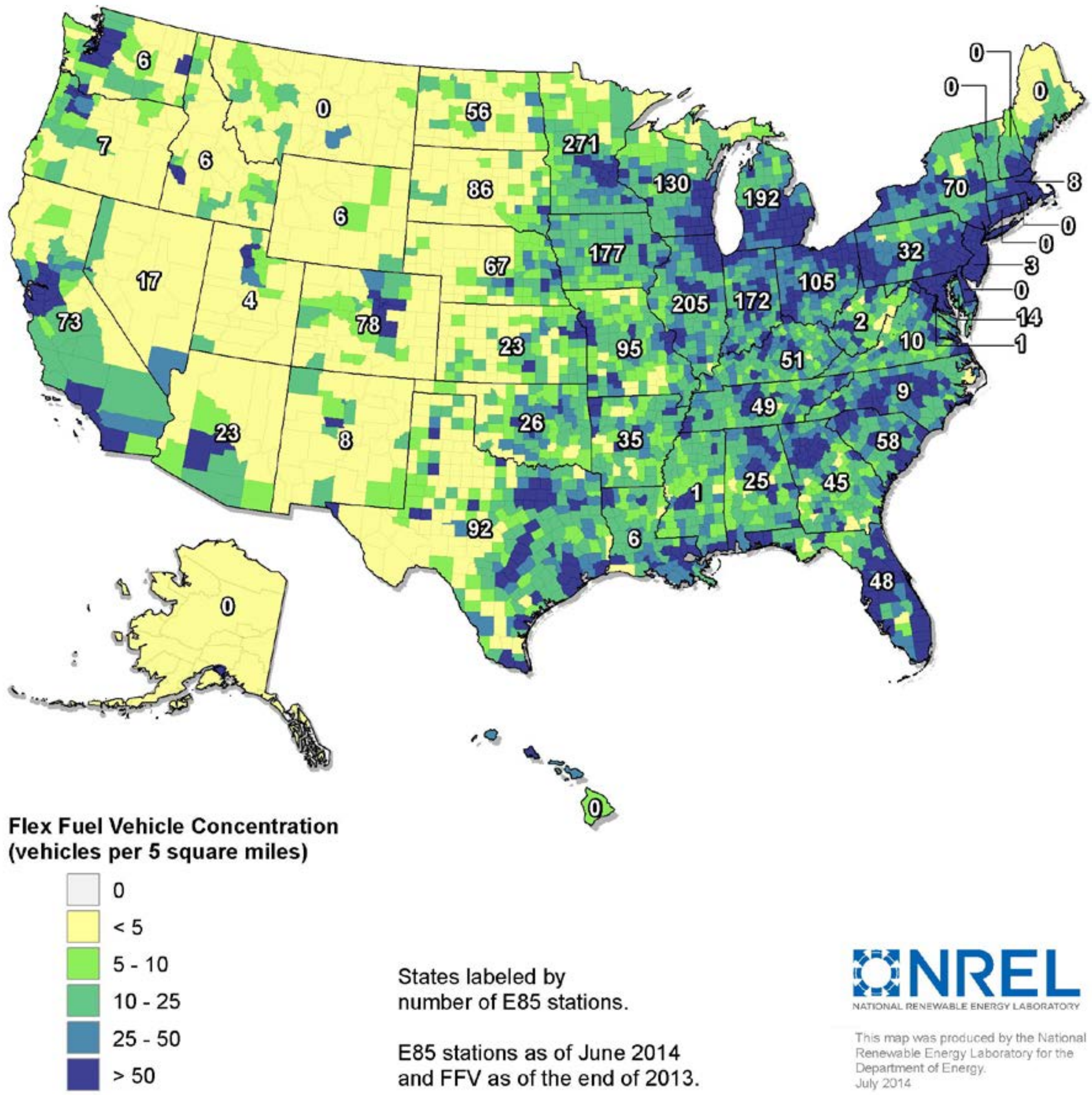

Figure 21. E85 stations and FFV locations by county

Sources: Vehicles: IHS Automotive (formerly Polk), https://www.polk.com; Stations: AFDC Alternative Fueling Station Locator, http://www.afdc.energy.gov/locator/stations/.

3.1.6 End-Use

All 243 million U.S.-registered gasoline vehicles are able to operate on E10. MY2001 and newer light-duty trucks and vehicles are approved by the EPA to operate on E15. At the end of 2012, 65% of the gasoline light-duty truck and vehicle population was 2001 and newer—however, some manufacturers approve the use of E15 in their vehicles while others do not[35].

[35] Vehicle populations were determined using 2012 IHS Automotive (formerly Polk) vehicle registration data purchased by NREL.

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The number of FFVs continues to increase and both domestic and foreign auto manufacturers offer FFVs capable of operating on any gasoline-ethanol blended fuel between E10 and E85 (Figure 22). For model year 2014, there were 90 models from seven manufacturers[36]. The National Highway Traffic Safety Administration establishes corporate average fuel economy (CAFE) standards and auto manufacturers receive a credit for each FFV sold, which helps them meet the overall regulation. Sales and production of FFVs are driven more by auto manufacturers' desire to obtain a CAFE credit than demand from customers (Barrionuevo and Maynard 2006). FFV CAFE credits are set to expire at the end of 2016 and it is unclear if auto manufacturers will continue to offer FFVs in future years. Beyond 2016, there is still a CAFE credit if auto manufacturers can demonstrate FFVs are using E85; however, nearly all states track only total ethanol sales for taxation purposes and do not differentiate between E10, E85, or other ethanol blends. This makes it nearly impossible for an auto manufacturer to meet the criteria.

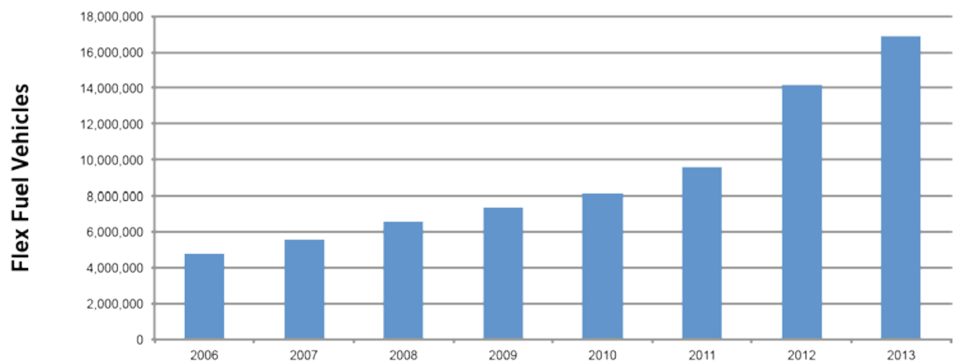

Figure 22. U.S. historical flexible fuel vehicles stock

Source: Polk (IHS), https://www.polk.com (data purchased annually).

3.1.7 Outlook and Trends

RFS fuel category requirements are based on feedstock type as well as greenhouse gas emission reductions and corn ethanol qualifies under the overall renewable fuel requirement. The EPA has the authority to adjust RFS volumes annually below EISA legislated volumes. In June 2015, the EPA proposed reducing the RFS renewable biofuel requirement for 2014-2016 due to the blend wall and limited cellulosic production[37]. Reducing the RFS biofuel requirement could make deployment of E15 or cellulosic ethanol more challenging.

At current levels of fuel ethanol use, the nation is essentially at the blend wall—where the entire market for E10 is met with conventional ethanol and ethanol production is matched with demand. The nearest term opportunities to expand the market are to sell more E15 and E85. If all MY2001 and newer vehicles, based on the 2012 vehicle population and gasoline consumption, always refueled with E15 and older gasoline vehicles refueled with E10, ethanol demand would

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[36] AFDC Light-Duty Vehicle Search allows users to identify alternative fuel vehicle availability by model year and manufacturer: http://www.afdc.energy.gov/vehicles/search.

[37] RFS renewable biofuel requirement rule history: http://www.epa.gov/renewable-fuel-standard-program/final-renewable-fuel-standards-2014-2015-and-2016-and-biomass-based.

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be 17.7 billion gallons[38]. In this scenario it would take time to develop E15 infrastructure, and market penetration would likely increase and expand from the Midwest as it did with E10.

In 2012, EIA projected E85 consumption of 151 million gallons, which indicates that the majority of FFVs are using E10 (EIA 2014d). Table 5 highlights market opportunities if FFV owners refueled more often with E85. As of the end of 2013, there were 17.4 million FFV owners; if they refueled with E85 more often, it would expand demand beyond the blend wall and there would more options for companies obligated to meet the RFS[39]. Blender dispensers (also called pumps) pose another, smaller potential growth market. Blender pumps allow retailers to sell several ethanol blends from the same dispenser and give FFV owners additional choices of mid-level ethanol blends such as E20 and E30, in addition to E85.

Table 5. U.S. Potential E85 Market with Greater Use by Flexible Fuel Vehicles

Potential E85 Market	
% of FFV refueling with E85	**potential E85 market* (billion gallons per year)**
20%	3.13
50%	7.81
100%	15.63

** Assumes fuel economy of 16.7 mpg (based on EPA average fuel economy of 21.6 miles/gallon for U.S. fleet between the years of 2004 and 2013, and a fuel economy reduction of 22.5% to account for lower energy density of E85). Also assumes vehicles are driven 15,000 miles/year and an FFV fleet of 17.4 million.*

Sources: Fuel economy and annual miles: "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 – 2014," EPA, October 2014, accessed October 20, 2014, http://www.epa.gov/otaq/fetrends-complete.htm; Fuel economy penalty for E85: Fueleconomy.gov "Flex-fuel Vehicles," accessed October 20, 2014, http://www.fueleconomy.gov/feg/flextech.shtml; FFV fleet-2013 data set: Polk (IHS): https://www.polk.com.

A longer-term possibility to increase ethanol deployment is a specialized engine optimized to use high octane fuel (e.g., research octane number [RON] 100), which could accommodate ethanol blends of 20% or greater or other high octane biofuel. However, these optimized vehicles are currently in a research phase and will not be available in the near term.

Other countries also have renewable fuel use requirements, which could provide additional markets for ethanol producers. Demand for exports will likely be impacted by the availability and price of sugarcane ethanol from Brazil.

[38] This calculation assumes E10 and E15 are universally available and that all MY2000 and older vehicles always refuel with E10 and all MY2001 and newer vehicles refuel with E15. Data is based on EIA 2012 gasoline consumption of 133 billion gallons per year and 2012 Polk (IHS) vehicle registration data with 82.9 million MY2000 and older and 160.2 million MY2001 and newer.
[39] NREL purchased FFV registration data from Polk (IHS): https://www.polk.com.

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3.2 Biobutanol

Biobutanol is a 4-carbon alcohol (butyl alcohol) produced from the same feedstocks as ethanol, including corn and other biomass. It qualifies for the RFS as a renewable biofuel if made from corn. While there are four isomers of butanol, the most active commercialization work is around isobutanol for blending with gasoline. There are two Clean Air Act provisions that allow for blending of up to 12.5% biobutanol with gasoline. Additionally, under the Octamix waiver, for which human health effects testing is ongoing, a 16% biobutanol blend is a legal fuel equivalent to E10 (GPO 2012). Biobutanol has an ASTM D7862 fuel quality standard for blends up to 12.5% with gasoline. It is important to ensure that biobutanol blended with ethanol gasoline combinations do not result in an oxygen content exceeding the EPA limit of 3.7%. The benefits of biobutanol when compared with ethanol are that it is less miscible with water and it has a higher energy content and lower Reid vapor pressure. One challenge is that more ethanol can be produced from a bushel of corn than biobutanol (Ramey 2007).

Table 6 shows the accessible public data about the prominent biobutanol ventures. Gevo owns the only operational U.S. biobutanol facility, which started operation in 2012 and was a retrofit of a corn ethanol plant. The plant is capable of producing either biobutanol or ethanol. Butamax is retrofitting a corn ethanol plant and expects to produce biobutanol by 2015. The near term outlook for production is limited, as production has been minimal and intermittent since 2012. In 2013, EPA reported biobutanol production of nearly 12,000 gallons (EPA 2014). At this time, major refiners cannot sell biobutanol blends for on-road use because it is not registered under 40 CFR (Code of Federal Regulations) Part 79 for companies with revenues exceeding $50 million, as required by the Clean Air Act. However, an additive manufacturer with sales of less than $50 million has been selling biobutanol and much of it has been used in specialty markets including marine, jet fuel, and also for conversion to para-xylene, a precursor to a plastic product.

Table 6. Commercial-Scale Biobutanol Plants in the United States

Company	Project Location	Technology Pathway	Feedstock Category	Capacity (MMGY)	Stage of Development
Butamax	Lamberton, MN	Biochemical	Corn	50	Under Construction
Gevo	Luverne, MN	Biochemical	Corn	18	Operational

Biobutanol companies produce a range of high-value products, including transportation fuel, with a goal of improving economic performance through diversification of product offerings. Primary co-products of biobutanol plants may include solvents/coatings, plastics, and fibers.

Oak Ridge National Laboratory has researched the compatibility of refueling equipment materials with biobutanol and found that equipment compatible with ethanol blends would also be compatible with biobutanol. UL announced in late 2013 that equipment certified under testing subject 87A (for blends above E10) also could retain certification if used with biobutanol. It is anticipated that biobutanol would be distributed by tanker truck and rail, with the potential for transportation in pipelines upon research demonstrating its safety. Biobutanol is compatible with existing vehicles at blends of 16% or less with gasoline and provides the same fuel economy as E10 (Butamax 2014).

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3.3 Biodiesel

3.3.1 Biodiesel Overview

Biodiesel is a domestically produced renewable fuel for use in diesel vehicles. Biodiesel can be manufactured from multiple feedstocks including vegetable oils, animal fats, or yellow grease. Biodiesel is produced by transesterification—a process that converts fats and oils into biodiesel and glycerin (a co-product). Biodiesel's physical properties are similar to those of petroleum diesel and they can be blended in any combination. Any blends of B5 (5% biodiesel, 95% petroleum diesel) or below meet ASTM fuel quality specification D975 for conventional diesel fuel and can be used in existing infrastructure and any compression-ignition engine intended for petroleum diesel. ASTM specification D7467 describes the properties of B6 to B20 blends. B20 is the most common higher-level biodiesel blend and engines operating on B20 have similar fuel consumption, horsepower, and torque to engines running on petroleum diesel. Some, but not all, engine and diesel vehicle manufacturers warrant the use of B20. B100 is typically used for blending with petroleum diesel and rarely used in engines due to higher costs, cold weather performance issues, and lack of compatibility with vehicles and infrastructure. B100 must meet ASTM standard D6751. In the first years of biodiesel production, fuel quality was an issue. Since the initial usage, industry has worked with ASTM to establish fuel quality standards and a voluntary quality assurance program known as BQ9000 to support higher quality fuels in the market. Biodiesel is distributed by truck, train, and barge; B5 in pipelines that do not carry jet fuel.

The market for biodiesel is relatively small but has been growing over the past five years —it currently accounts for approximately 2% of the 50 billion gallon annual diesel market (EIA 2014e). Biodiesel demand is driven primarily by the RFS under two subcategories in the advanced biofuels requirements—biomass-based diesel and other advanced biofuels. 2013 was the first year biodiesel production and consumption exceeded the RFS requirement for biomass-based diesel and excess production was used to meet the overall advanced biofuel requirement of the RFS. Several states also have biodiesel mandates. B5 has long been approved for use in home heating oil and there remains more growth for biodiesel use in this market as ASTM International recently approved up to B20 in home heating oil.

Studies conducted by both DOE and USDA conclude that use of soybean biodiesel (the most energy intensive major feedstock) reduces fossil energy use by more than 85% in comparison to petroleum diesel (Pradhan et al. 2011). An Argonne National Laboratory study also showed a 94% reduction in well-to-wheels greenhouse gas emissions for soy-based biodiesel (Huo et al. 2008). Notably, these reductions per gallon of B100 used are much larger than those obtainable through the use of corn-derived ethanol. Use of biodiesel in older on-highway diesel engines also reduces emissions of unburned hydrocarbons, carbon monoxide, sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, and particulate matter. For 2010 and newer model year diesel engines, tailpipe emissions are controlled using catalysts and filters such that fuel composition has little effect on emissions.

Biodiesel prices are directly correlated with petroleum diesel prices, and because plants use a variety of feedstocks, pricing depends on overall production costs but does not correlate with one particular feedstock as ethanol often does with corn (Figure 23).

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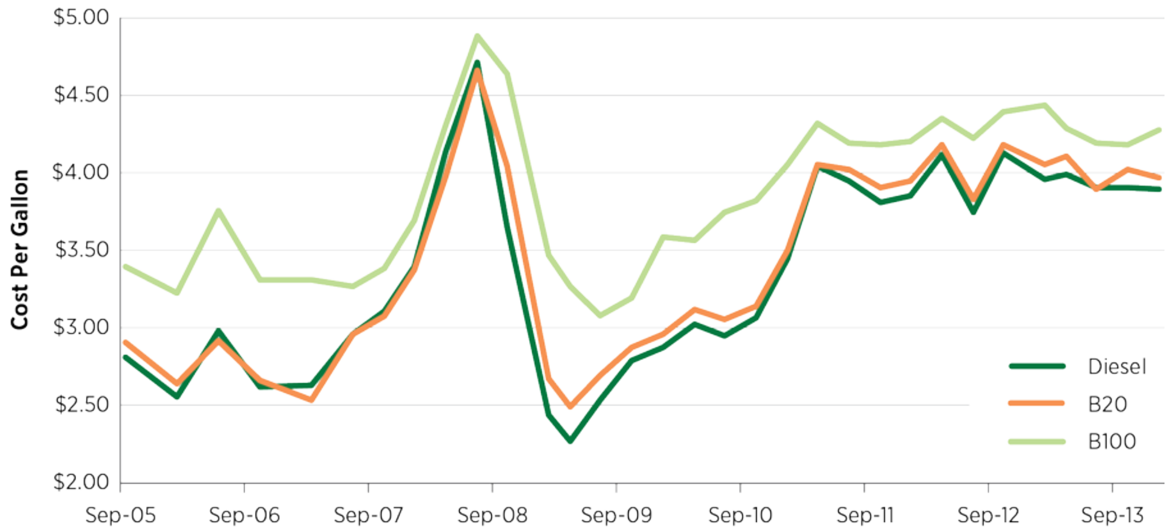

Figure 23. U.S. retail biodiesel prices

Source: Clean Cities Alternative Fuel Price Report (quarterly 2005–2014), http://www.afdc.energy.gov/fuels/prices.html.

R&D on biodiesel production has primarily focused on improved separation processes for product clean up and the development of inorganic heterogeneous (solid) and enzyme catalysts for the transesterification reaction. The majority of research on separation processes is proprietary and has been conducted by the biodiesel manufacturers and has resulted in incremental improvements in the efficiency of their processes. Research on heterogeneous and enzyme catalysts has been published in the public domain, but none of these technologies has been adopted by biodiesel producers.

A major area of research sponsored by the biodiesel industry has been in the area of the performance of biodiesel blends in the fuel distribution system and in engines. This research led to significant changes to the ASTM specifications for B100 and biodiesel blends that improved storage stability and cold weather operation. Additional research in these areas, as well as on the performance of biodiesel blends with emission control catalysts and filters, is ongoing.

3.3.1.1 Feedstocks

Biodiesel in the United States is produced from various lipid feedstocks such as vegetable oils, animal fats, and waste greases. About 50% of the biodiesel plants do not rely on one type of feedstock and use multiple sources to ensure optimal feedstock supply security (Kotrba 2014).

Soybean oil is the largest biodiesel feedstock, providing more than 50% of the total input (Figure 24). About 5.5 billion pounds of soybean oil were used for biodiesel production in 2013, which is about 27% of the soybean oil produced that year (EIA 2014b; USDA-ERS 2014b).

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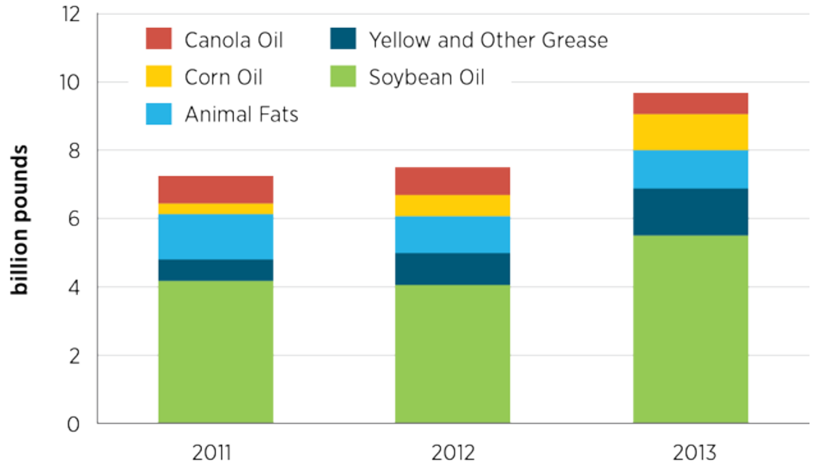

Figure 24. U.S. inputs to biodiesel production

Source: EIA 2014b.

About 1 billion pounds of corn oil were used for biodiesel production in 2013, making it the second largest feedstock source (Figure 24). Historically, corn oil has not been a viable biodiesel feedstock due to its relatively high cost and high value as edible oil. However, production of low-cost, non-food grade quality corn oil by many ethanol plants in response to difficult market conditions has resulted in a substantial increase in corn oil use for biodiesel[40]. Other vegetable oils used in biodiesel production include canola oil (about 650 million pounds in 2013) and very small amounts of sunflowerseed and cottonseed oils.

The use of yellow grease (used cooking oil) and other recycled oil feedstocks for biodiesel production has also increased due to low cost and availability of the resource. Consumption of yellow grease for biodiesel production was about 471 million pounds in 2011 or 24% of total feedstock production (Figure 24). This consumption increased substantially to about 1 billion pounds in 2013 or 50% of total yellow grease production that year, making it the third largest feedstock source for biodiesel production.

Animal fats provided about 11% of the total biodiesel feedstock supply in 2013, or about 1.1 billion pounds (Figure 24).

3.3.1.2 Historical Production, Consumption, and Capacity

Both biodiesel production and consumption have expanded over the past decade reaching total production in 2013 of 1.34 billion gallons (EIA 2014d); however, there have been interesting market dynamics (Figure 25). Between 2007 and 2009 production exceeded domestic consumption and exports to European nations were common due to higher prices, but that opportunity declined in 2010 due to European legislation. Fuels companies were taking advantage of the U.S. production tax credit and exporting lower cost biodiesel while the European Union issued a protectionist policy. This, likely combined with uncertainty about renewal of the federal biodiesel production tax credit, led to a period of lower production.

[40] Corn oil is a co-product at ethanol plants and does not impact ethanol production.

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Current and future production could be impacted by an EPA proposal to lower the RFS advanced biofuels volume; however, at the time of this report, EPA had not finalized 2014 requirements[41]. The availability of the biodiesel producer tax credit also impacts production.

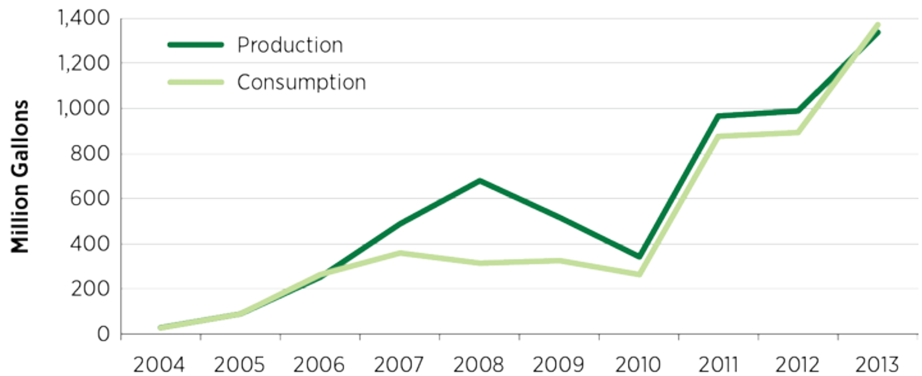

Figure 25. U.S. biodiesel production and consumption

Source: EIA Annual Energy Review, Table 10.4, http://www.eia.gov/totalenergy/data/annual/index.cfm.

In 2013 there were approximately 155 biodiesel plants with a total industry production capacity of more than 2.2 billion gallons in 41 states (Figure 26) (EIA 2014e).

[41] RFS advanced biofuel category volume requirement in 2013 was 2.75 billion gallons; the 2014 proposal is 2.2 billion gallons.

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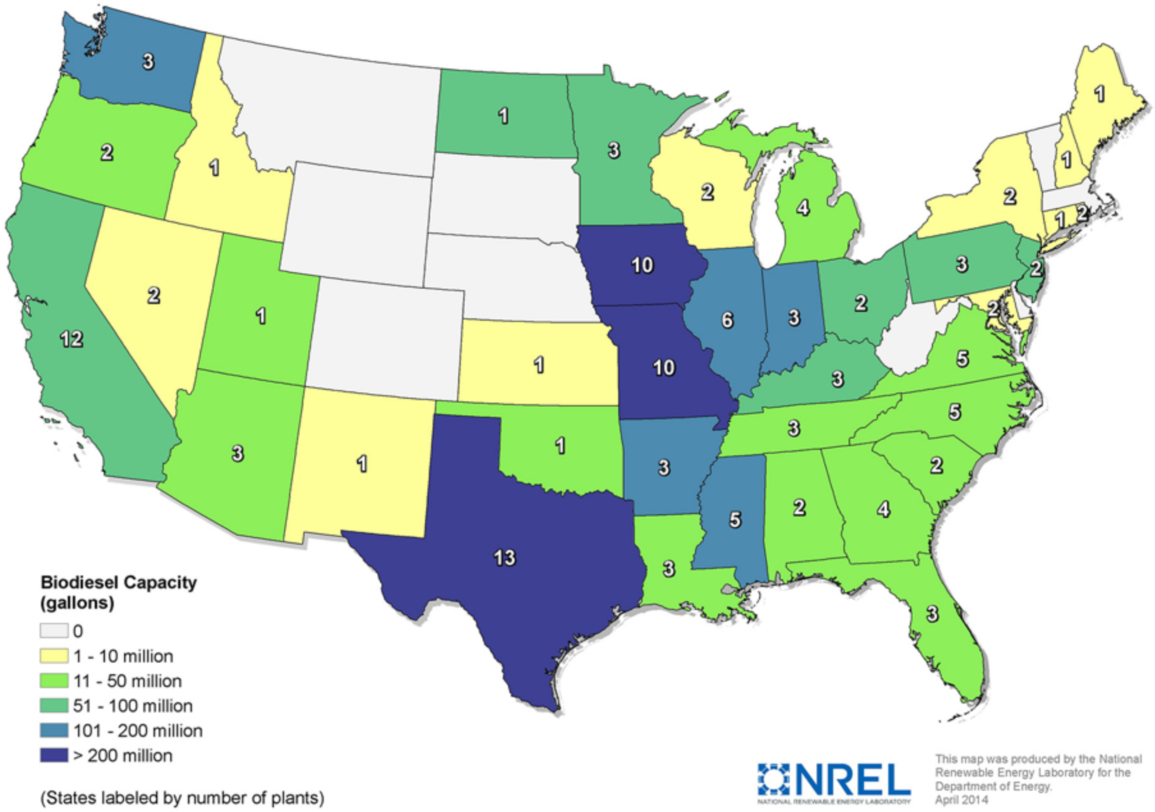

Figure 26. Biodiesel plants by state (as of April 2014)

Source: *Biodiesel Magazine* USA Plants List, last accessed May 1, 2014, http://www.biodieselmagazine.com/plants/listplants/USA.

The average biodiesel plant size is 16 million gallons, and small plants are less able to deal with financial challenges than larger plants. In terms of production capacity, the largest biodiesel producer is Renewable Energy Group (REG), which operates eight plants with a total production capacity of more than 250 million annual gallons—capable of providing roughly 20% of 2012 and 2013 total production (*Biodiesel Magazine* 2014). Other large producers include traditional agricultural commodity processers and oleochemical producers: Ag Processing (120 million gallon capacity), Archer Daniels Midland (ADM) (135 million gallons capacity), Cargill (83 million gallons capacity), Louis Dreyfus (80 million gallon capacity), and many others. Several companies focused exclusively on biodiesel production also have significant production capacity, including RBF Port Neches, with the largest capacity plant in North America at 180 million gallons.

As shown in Figure 27, biodiesel plants have long operated below capacity, but 2013 saw an increased utilization rate over past years based on production versus installed capacity. The reason plants are idle or closed is typically related to economic conditions where costs exceed market prices or periods when the federal biodiesel producer tax credit was unavailable. It has been challenging for biodiesel plants to remain profitable without the producer tax credit. Insufficient cash flow and limited or no access to credit also impacts the ability to operate. Older plants are less likely to be efficient and may rely on a single feedstock while newer or upgraded

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plants achieve greater efficiencies and are capable of using several feedstocks, which can improve margins because they can use the most affordable and available feedstock.

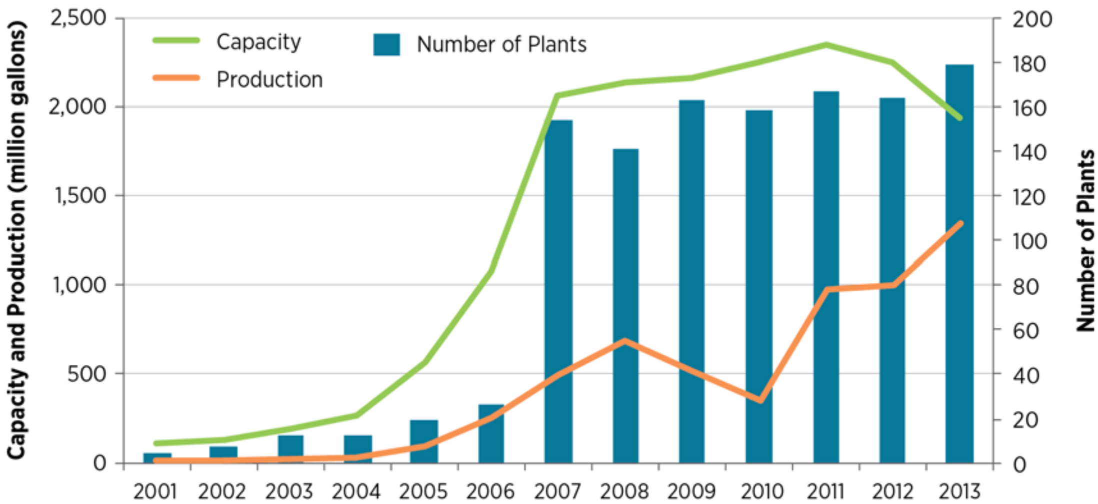

Figure 27. U.S. historical biodiesel plant capacity

Source: EIA 2014e.

3.3.1.3 Production Cost

Biodiesel production costs vary with the feedstock being used; plant size, type and design; when it was built; and how it is managed. Iowa State University developed a model to track Iowa biodiesel profit margins and production costs over time based on Iowa biodiesel prices and costs for soybean oil, methanol, and other operating costs (Hofstrand 2014b). Over the past seven years, soybean oil accounted for 85% of operating costs at an average Iowa biodiesel plant with lower costs for methanol and other operating costs with production costs ranging between $2.50 to $5.50 between April 2007 and April 2014 (Figure 28). Biodiesel plants using other feedstocks such as corn oil, canola oil, tallow, and waste grease would experience different costs; however, feedstock costs typically comprise 70%–95% of overall operation costs (Tao and Aden 2009). Energy costs are not significant and are not tracked separately as they are for ethanol.

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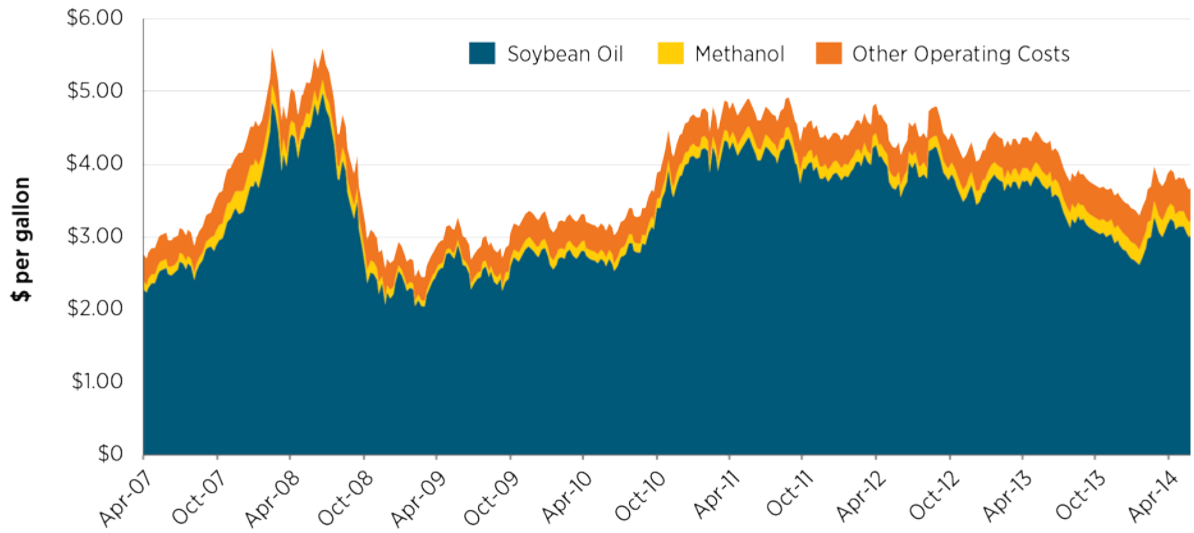

Figure 28. U.S. soybean-based biodiesel production cost trends

Source: "Historical Biodiesel Operating Margins," Center for Agricultural and Rural Development, Iowa State University, last accessed June 9, 2014: http://www.card.iastate.edu/research/bio/tools/hist_bio_gm.aspx.

3.3.1.4 Co-Products Overview

The only co-product of biodiesel production is glycerin, which is used in food, hygiene, and pharmaceutical products. Each gallon of biodiesel produced results in 1.05 pounds of glycerin. Biodiesel production has resulted in an oversupply of glycerin for U.S. markets leading to low prices for crude glycerin of around $0.10/pound with higher prices for upgraded or refined glycerin (Kotrba 2014). Research is focused on other uses for glycerin with an emphasis in the areas of algae, syngas, and yeast production.

One of BETO's technology transfer successes is ADM's 100,000 metric ton renewable propylene glycol plant. ADM operates this plant for converting glycerin from biodiesel production into propylene glycol. The technology received an American Chemical Society (ACS) green chemistry award in 2014, and the renewable propylene glycol (U.S. Pharmacopoeia [USP] Specifications Grade, USDA certified) is a component of several other USDA-certified green product lines (mostly heat transfer fluids).

3.3.1.5 Economic Impacts of Biodiesel

A recent study conducted for the National Biodiesel Board indicated that at the projected 2013 market size of 1.7 billion gallons, total economic impact would be $16.8 billion and support more than 62,000 jobs (NBB 2013).

According to the same National Biodiesel Board study, from 2005–2013, biodiesel production in the United States increased from 209 million gallons (747,000 tons) to 1.13 billion gallons (just more than 4 million tons). With this increased production:

- The economic impact of biodiesel increased from $1.4 billion annually in 2005/06 to $10.6 billion in 2011/12.

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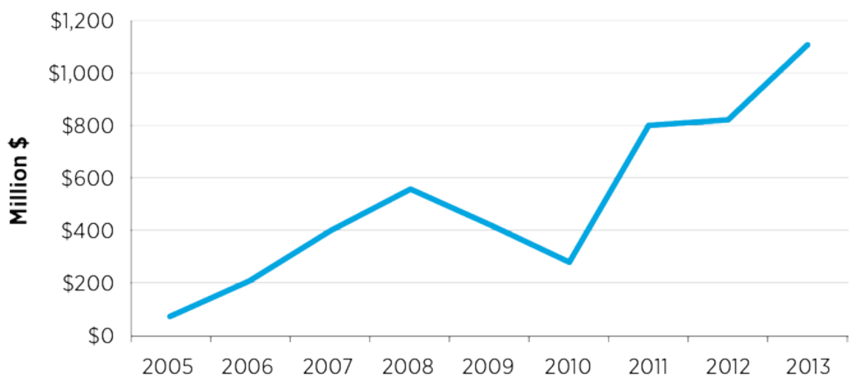
- The number of jobs supported increased from just fewer than 7,000 in 2005/06 to more than 50,000 in 2011/12.
- Wage impacts increased from $260 million to $2.2 billion, implying that the average job supported by the biodiesel sector paid a wage of approximately $43,000/year in 2011/12.

3.3.2 Policies that Affect this Market

Biodiesel has been primarily impacted by two policies—the RFS and the biodiesel production tax credit[42]. The biodiesel production tax credit was originally established by The American Jobs Creation Act of 2004; it has expired and been retroactively reinstated several times through other legislation but expired again at the end of 2014. The tax credit was $1.00/gallon or $0.50/gallon produced based on feedstock type with pure vegetable oil receiving the higher credit and waste products receiving the lower credit. The estimated cumulative federal investment for the biodiesel production tax credit since its inception is $4.7 billion (Figure 29)[43]. The availability of the tax credit has influenced production—as production costs sometimes exceed the price paid for biodiesel (Figure 23, Figure 28). Between 2005 and 2011 there was a small producer tax incentive of $0.10/gallon for the first 15 million gallons of biodiesel production at facilities using pure vegetable oils as feedstock with capacity of 60 million or fewer gallons/year. Additional federal investment in the biodiesel industry was allocated through grants, loan guarantees, and tax credits for refueling infrastructure. All significant federal incentives have expired and the primary driver of the current market is the obligated volumes of the RFS.



Calculated by multiplying biodiesel production by tax incentive of $1.00/gallon for 66% of production (vegetable oil source) and $0.50/gallon for 34% of production (waste source).

Figure 29. Estimated federal investment in the biodiesel production tax credit

3.3.3 Biodiesel Trade

The United States both imports and exports biodiesel with trade dynamics largely affected by current policies (Figure 30). In 2013 there were imports from 12 nations with Argentina

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[42] This section covers federal incentives and policies. States also may have incentives and policies. This information is available from the Alternative Fuels Data Center Laws and Incentives website: http://www.afdc.energy.gov/laws.

[43] This is based on the assumption that 65% of biodiesel production receives the $1.00/gallon credit and 35% receives the $0.50/gallon credit based on a three-year historical average use of feedstocks. The $4.7 billion estimate could be somewhat higher or lower depending on actual feedstocks used since 2005.

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accounting for 61% of the total and Germany and Indonesia with 19% and 17%, respectively (EIA 2014c). The high level of exports in the mid-2000s was a result of policies that allowed inexpensive imported biodiesel to be blended with petroleum diesel to receive the U.S. biodiesel production tax credit, which was then exported to European markets—this was known as "splash and dash." This practice was discontinued with policy changes in Europe and the United States leading to lower exports, which were also the result of increased domestic use of biodiesel to meet the RFS volumes. The United States exported to 10 nations in 2013 with Canada accounting for 43% of that total and Malaysia and Spain representing more than 30% (EIA 2014c).

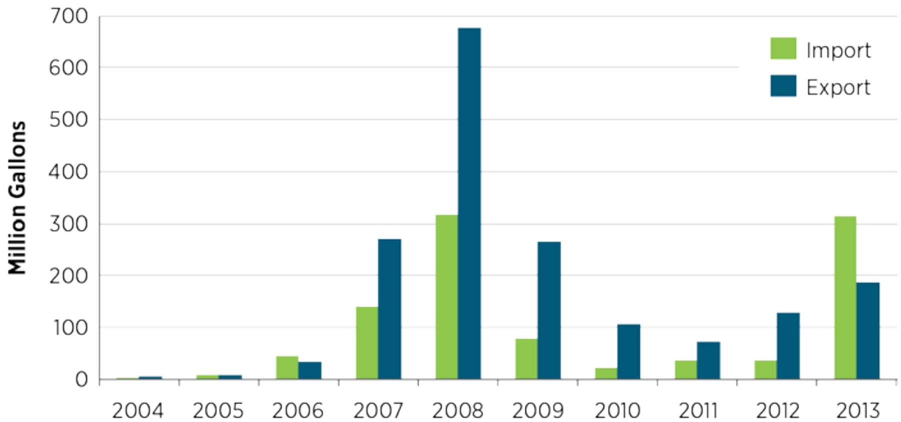

Figure 30. U.S. historical biodiesel imports and exports

Source: EIA Monthly Energy Review, Table 10.4, http://www.eia.gov/totalenergy/data/monthly/#renewable.

3.3.4 Infrastructure

The same patchwork of infrastructure regulation that applies to ethanol blends of more than E10 also applies to biodiesel blends of more than B5 (refer to section 3.1.5). OUST's existing federal tank code allows storage of up to B20 and its biofuels guidance allows higher blends if a manufacturer provides a letter stating compatibility (EPA 2011). All existing steel and fiberglass underground storage tank manufacturers have issued letters stating compatibility with B100; however, the decades long usage of tanks means that there are tanks installed by manufacturers that are no longer in business and these tanks cannot store blends above B20[44]. UL-listed B20 equipment became available in 2013; however, most B20 stations were already in operation and had likely received a waiver from their AHJ.

Diesel use is predominately related to the trucking industry's consumption pattern and not personal vehicles. This is why, broadly speaking, most retail stations offering diesel are located along major trucking routes. This is also the reason why biodiesel stations are situated primarily in urban centers and along major highways. Those outside of these locations are typically private stations serving the fleets of the Department of Defense, other federal agencies, and local governments. Of the more than 700 refueling stations offering B20, 325 are open to the public

[44] A list of biodiesel compatible tanks, associated equipment, and UL-listed dispensers and hanging hardware is available on the AFDC: http://www.afdc.energy.gov/fuels/biodiesel_infrastructure.html.

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(Figure 31). A growth opportunity for biodiesel is at some of the 2,500 truck stops across the nation, since less than 20 sell B20 as of August 2014[45].

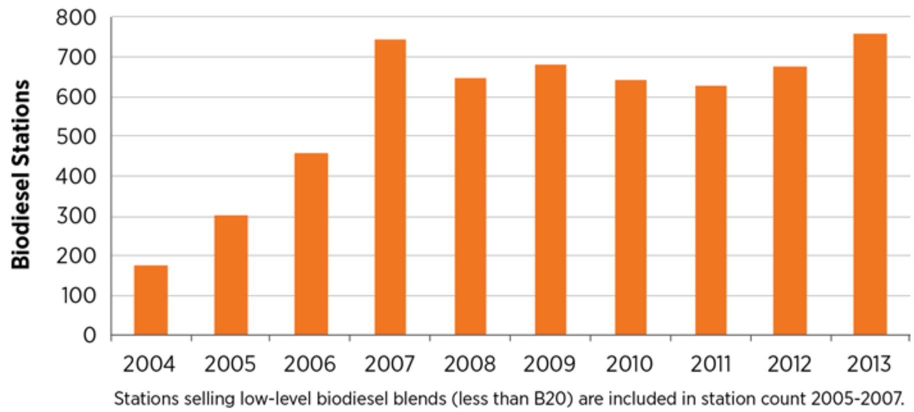

Figure 31. U.S. historical B20 refueling stations

Source: Alternative Fuels Data Center, http://www.afdc.energy.gov/fuels/stations_counts.html.

3.3.4.1 End-Use

In 2012 there were 6.8 million light-duty diesel vehicles and 6.9 million medium- and heavy-duty diesel vehicles registered in the United States[46]. All of these vehicles can use B5 without any modifications to vehicles or infrastructure. There are 13 MY2014 cars, pickup trucks, and vans approved by the manufacturer for use with B20 and at least 34 engines approved for B20 use in medium- and heavy-duty vehicles and trucks. The National Biodiesel Board provides information on biodiesel blend approvals for vehicles and engines for each model year[47]. Because of their high fuel economy, the number of light-duty diesel vehicles is expected to grow to meet CAFE standards.

There is an opportunity to increase biodiesel use in the home heating oil market, which is concentrated in the Northeast. Biodiesel blended with home heating oil is marketed as Bioheat fuel. B5 can be used in standard home heating oil equipment and a recent National Oilheat Research Alliance (NORA) survey of 35,000 buildings using B5 reported no issues (NORA 2014). Since 2008, ASTM D396 Standard Specification for Fuel Oils has allowed a blend of up to B5 in home heating oil. NORA research results on blending B20 with standard and low-sulfur home heating oil show no impact on heating equipment. This led to ASTM International approving the use of B6–B20 under ASTM D396 as of December 2014.

3.3.5 Outlook and Trends

Federal policies are the primary drivers for biodiesel because it cannot be produced at a price competitive with petroleum diesel in current market conditions. Future growth of the biodiesel

[45] Based on NREL analysis of data from the AFDC Alternative Fueling Station Locator: http://www.afdc.energy.gov/locator/stations.
[46] Data purchased from Polk (IHS). Medium- and heavy-duty are classified as vehicles with a gross weight of more than 14,000 pounds.
[47] National Biodiesel Board OEM Information: http://www.biodiesel.org/using-biodiesel/oem-information.

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market will be highly dependent on the policy environment. As research on new feedstock sources comes to fruition, feedstock costs may stabilize or even decline, improving economics. Biodiesel producers are in competition with renewable hydrocarbon diesel producers for feedstock. Additionally, there are no federal policies that promote the use of biodiesel in home heating oil—an area for potential market growth.

The outlook for biodiesel suggests industry consolidation and trends toward higher production at fewer, larger plants. Because feedstock availability and price dominate the economics of biodiesel production, larger producers have an advantage in that they have the financial resources to contract for feedstock on a large scale. In many cases, smaller producers have been forced to purchase feedstock at higher prices on the commodity markets. Industry analysts expect continued consolidation (Sims 2014). This consolidation will take the form of larger average plant size, as well as production companies operating (but not necessarily owning) multiple production plants to gain economy of scale and buying power in feedstock procurement. Nevertheless, there will continue to be a fairly large number of small producers utilizing waste grease that is collected from local restaurants and food processors.

3.4 Renewable Hydrocarbon Biofuels

Renewable hydrocarbon transportation fuels (also called "green" hydrocarbons, biohydrocarbons, drop-in biofuels, and sustainable or advanced hydrocarbon biofuels) are fuels produced from biomass sources through a variety of biological, thermal, and chemical processes. These products are similar to petroleum gasoline, diesel, or jet fuel in chemical makeup and therefore are considered fully infrastructure-compatible fuels. It is anticipated that these fuels can be used in vehicles with no engine modifications required and can utilize existing petroleum fuel pipelines and retail distribution systems. This eliminates the infrastructure-compatibility concerns associated with currently available biofuels.

Renewable hydrocarbon biofuels are produced from various biomass sources. These include lipids (vegetable oils, animal fats, greases, and algae), MSW, and cellulosic material (crop residues, woody biomass, and others). The availability of these resources was evaluated earlier in the feedstock section. Several conversion processes are being explored for the production of renewable hydrocarbon biofuels:

- Traditional hydrotreating used in petroleum refineries, which involves reacting the feedstock (lipids) with hydrogen under elevated temperatures and pressures in the presence of a catalyst
- Fermentation, which uses a biochemical deconstruction process similar to that used with cellulosic ethanol with organisms that convert sugars to hydrocarbons
- Catalytic conversion of sugars, which involves a series of catalytic reactions to convert carbohydrate stream into hydrocarbon fuels
- Gasification, in which biomass is thermally converted to syngas and catalytically converted to hydrocarbon fuels
- Pyrolysis, which involves the chemical decomposition of organic materials at elevated temperatures in the absence of oxygen to produce a liquid pyrolysis oil that can be

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upgraded to hydrocarbon fuels, either in a stand-alone process or as a feedstock for co-feeding with crude oil into a standard petroleum refinery

- Hydrothermal processing, which uses high pressure and moderate temperature for chemical decomposition of biomass or wet waste materials to produce an oil that may be catalytically upgraded to hydrocarbon fuels.

Renewable gasoline, also known as biogasoline or "green" gasoline, is a collection of gasoline-boiling-range hydrocarbons derived from biomass, suitable for use in spark-ignition engines and meeting ASTM specification D4814 in the United States and EN 228 in Europe. Companies that have been working toward developing renewable gasoline include Cool Planet, KiOR, Sundrop Fuels, Virent, and Primus Green Energy.

Renewable diesel, also called "green" diesel, is a transportation fuel derived from biomass sources suitable for use in diesel engines that meets the ASTM D975 specification in the United States and EN 590 in Europe. Renewable diesel is distinct from biodiesel. While renewable diesel is chemically similar to petroleum diesel, biodiesel is a mono-alkyl ester which has different physical properties and hence different fuel specifications (ASTM D6751 and EN 14214). The two fuels also are produced through very different processes. While biodiesel is produced via transesterification, renewable diesel is produced through various processes such as hydrotreating/isomerization, gasification, pyrolysis, and other thermochemical and biochemical means. Moreover, biodiesel is produced exclusively from lipids whereas renewable diesel is produced from lipids and cellulosic biomass. Companies in the United States working toward developing renewable diesel include Amyris, Honeywell International Inc.'s UOP, Cool Planet, Fulcrum Bioenergy, Velocys, and Clear Fuels, among others.

Renewable jet fuel, also called "biojet" or aviation biofuel, is a biomass-derived fuel that can be used interchangeably with petroleum-based aviation fuel. Certain biojet fuel can now be blended up to 50% with conventional commercial and military jet (or aviation turbine) fuel through requirements in the ASTM D7566 specification. The following two fuel categories are approved by the standard:

- Hydrogenated esters and fatty acids (HEFA) fuels derived from used cooking oil, animal fats, algae, and vegetable oils (e.g., camelina)
- Fischer-Tropsch (FT) fuels using solid biomass resources (e.g., wood and crop residues).

Blending of these synthetic paraffinic kerosene (SPK) fuels is required because they lack sufficient aromatic hydrocarbons that are present in the conventional jet fuel. While aromatic hydrocarbons are limited in jet fuel to prevent smoke formation during combustion, a minimum aromatic content is needed to cause elastomer swell in aircraft fuel systems and increase fuel density. Three other pathways are being evaluated for certification:

- Alcohol-to-jet (ATJ) pathway, a form of SPK, with certification expected in 2014
- FT-derived synthetic kerosene with aromatics (SKA), which targets the production of aviation biofuels that contain aromatics and thus could be used without blending, with certification expected in 2015 (Davidson et al. 2014)

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- Hydrotreated-depolymerized cellulosic-jet pathway using a pyrolysis process, with certification expected in 2015 (Davidson et al. 2014).

There are other processes in development, such as HEFA-derived SKA and ATJ-derived SKA.

Since 2008, several airlines (Lufthansa, KLM, United, Alaska Airlines, and others) and aircraft manufacturers (e.g., Boeing and Airbus) performed flight tests with various blends containing up to 50% of the two approved forms of SPK biojet fuel. Additionally, flight tests were performed by military aircrafts of the U.S. Navy and U.S. Air Force. U.S. companies working toward developing renewable jet fuel include Amyris, Solazyme Inc., AltAir Fuels, Honeywell International Inc.'s UOP unit, LanzaTech, Fulcrum Bioenergy, Red Rock Biofuels, and others.

3.4.1 Commercialization of Renewable Hydrocarbon Biofuels

A study of U.S. renewable hydrocarbon biofuels producers was conducted to understand the status of the renewable hydrocarbon biofuels industry at the end of calendar year 2013 (Schwab et al. 2015). As of the end of 2013, there was only one plant (the KiOR facility in Mississippi) producing renewable hydrocarbon biofuels at commercial scale[48]. The total installed U.S. commercial capacity for renewable hydrocarbons at year-end 2013 was approximately 224 million gallons per year; however, only 13 million gallons per year of capacity was operational at the end of 2013 and only 514,627 gallons were produced in 2013 (EPA-RFS2 2013). The status of U.S. renewable hydrocarbon capacity as of the end of 2013 is summarized in Table 7.

Table 7. Status of U.S. Commercial-Scale Renewable Hydrocarbon Capacity at the End of 2013

Company	Project Location	Technology Pathway	Feedstock Category	Capacity [MMGY]	Operational Year (Anticipated)
Diamond Green Diesel	Norco, LA	Hydrotreating/ Isomerization	Vegetable Oils, Fats, and Greases	136	(2014)
Dynamic Fuels LLC	Geismar, LA	Hydrotreating/ Isomerization	Vegetable Oils, Fats, and Greases	75	2010 [Idled in 2013]
KiOR	Columbus, MS	Thermochemical Pyrolysis	Woody Biomass	13	2013

Source: Schwab et al. 2015.

Figure 32 summarizes the characteristics of the 17 renewable hydrocarbon facilities included in this survey report. Figure 32 also shows the various combinations of technology pathways and feedstock being pursued at these renewable hydrocarbon facilities. The six feedstock types used across the four technology pathways indicate the diversity of the developing renewable hydrocarbon production capability in the United States.

[48] The KiOR facility in Mississippi was subsequently idled in 2014.

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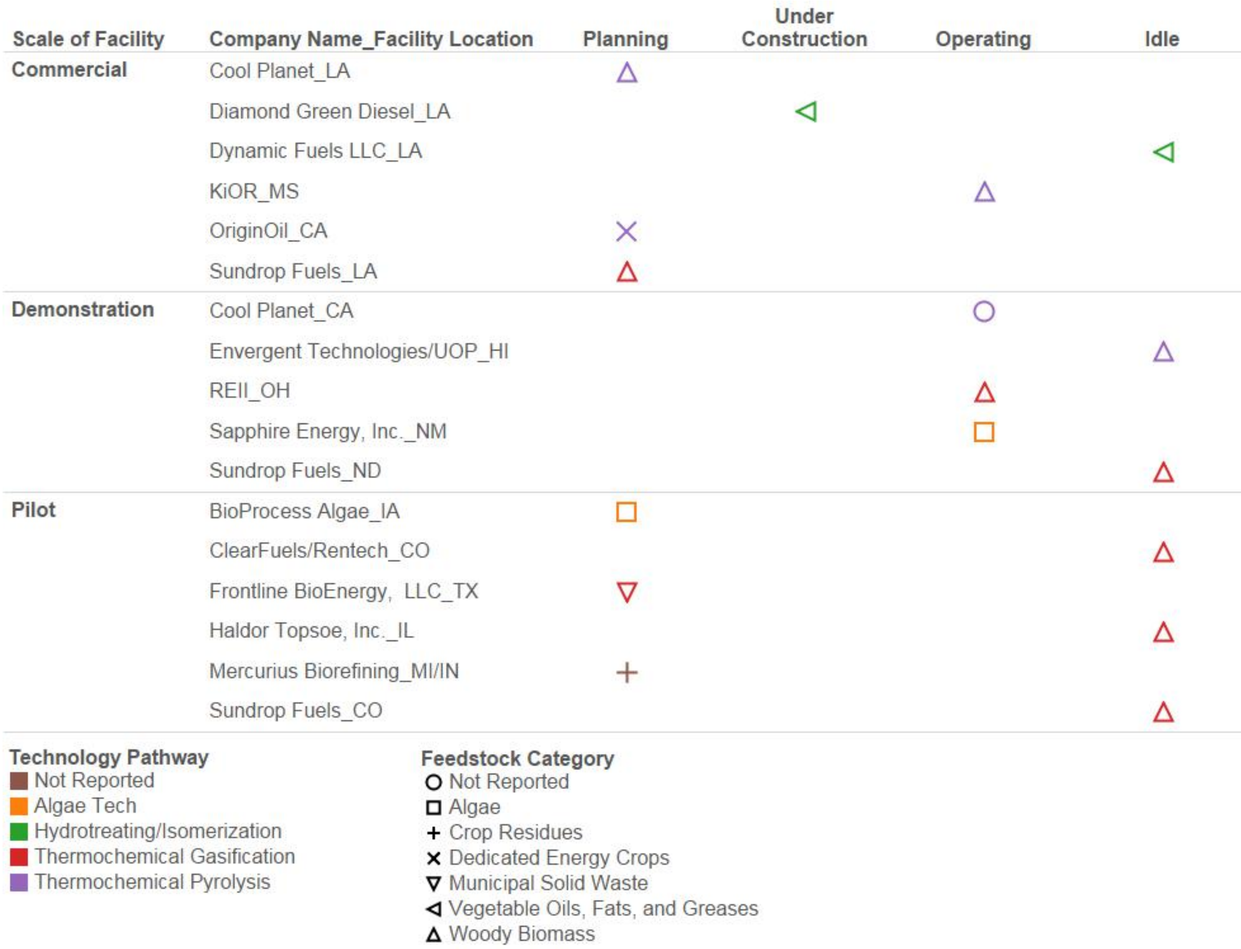

Figure 32. Characteristics of U.S. renewable hydrocarbon biofuel facilities at the end of 2013

Source: Schwab et al. 2015.

During this 2013 study, no pilot-scale facilities were identified as operating or under construction—though three pilot facilities were in the planning stage of development. At the demonstration scale, three facilities were operating (each with a different technology pathway and feedstock combination), but none were currently under construction. The study documented three pilot, two demonstration, and one commercial facility that were idle at the end of 2013. Four of these six idle facilities used the thermochemical gasification technology pathway, but development of this technology pathway still continues at other facilities. All of the thermochemical gasification facilities used woody biomass as feedstock, with the exception of the Frontline BioEnergy facility, which plans to use municipal solid waste. The two hydrotreating/isomerization commercial facilities were using vegetable oils, fats, and greases as feedstock.

3.4.1.1 Production Costs

The costs for producing renewable hydrocarbon biofuels are not well known, and estimates range widely. Milbrandt et al. (2013) conducted a literature review of public sources and reported

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production costs for various production processes. The study reports costs for renewable diesel and jet fuel production via hydroprocessing of soybean oil at about $3.82–$4.39/gallon ($3.61–$4.15/gge) and $4.09–$4.69/gallon ($3.81–$4.37/gge) in 2010 dollars, respectively. The study also reports production costs of renewable diesel and gasoline produced via gasification of corn stover followed by FT synthesis at $4.50–$5.00/gge in 2007 dollars, depending on the operating temperature of the gasifier, along with another estimate of $6.45/gallon ($6.09/gge) in 2008 dollars. Biojet fuel production via gasification and FT synthesis is reported at $4.00/gge from corn stover, $5.50/gge from switchgrass, and about $5.80/gge from short-rotation woody crops in 2007 dollars. A selling price of $3.24/gge for the KiOR catalytic fast pyrolysis process was reported, although the source does not provide analysis details and it is unclear what year the costs were indexed.

3.4.2 Outlook and Trends

The outlook for renewable hydrocarbon fuels, based on market trends, is mixed. The substantial continued federal investment into research and development on renewable hydrocarbon fuel pathways and the number of facilities being planned at various scales suggest continued interest and favorable longer-term trends toward producing renewable hydrocarbon biofuels. The number of idle facilities highlights the nearer-term operational challenges. As with cellulosic ethanol, the RFS is a significant driver encouraging hydrocarbon biofuel development. Hydrocarbon biofuels are able to qualify for multiple categories of RINs—such as advanced biofuels, biomass-based diesel, and cellulosic biofuels. For 2014, the EPA has proposed RFS target volumes of 920 million gallons of advanced biofuels, 1.26 billion gallons of biomass-based diesel, and 17 million gallons of cellulosic biofuels.

3.5 Biofuels Market Outlook

The EIA, in its 2014 Annual Energy Outlook (AEO), provides forecasts of ethanol, biodiesel, and advanced biofuels production through 2040 (EIA 2014d). The 2014 AEO projects that overall renewable fuels production will increase modestly on average by 0.7% per year during the 2013–2040 period, with more rapid growth occurring during the first 10 years, and then leveling off during the out years. The 2014 Annual Energy Outlook takes into consideration many of the different policies and regulations that can affect energy markets, including the RFS. In the 2014 AEO, ethanol production is expected to remain relatively flat, and biodiesel production is expected to remain constant during the 2013–2040 period. It should be noted that the 2014 AEO assumes that the EPA RFS requirements for advanced biofuels will increase slowly after 2015, but not reach the 2022 regulated values.

4 Biopower

Biomass power, or biopower, is the use of biomass resources to generate electricity. There are five major types of biopower-generation technologies: combustion, co-firing, gasification, anaerobic digestion, and pyrolysis. Combustion is used by most biopower plants today—bioenergy feedstock is burned directly to produce steam that turns an electricity-generating turbine. The steam could also be used for industrial processes or to heat buildings in combined heat and power (CHP) facilities. Co-firing power plants substitute solid biomass for a portion of the fuel in use. In gasification systems, solid biomass is heated in a restricted supply of air to produce an energy-rich gas that can fuel steam generators, combustion turbines, combined cycle technologies, or fuel cells. Anaerobic digestion (AD) is a biological process in which

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microorganisms break down biodegradable material in the absence of oxygen. One of the end products is biogas, comprised primarily of methane, carbon dioxide, and other trace elements. The methane is usually burned in a boiler to produce steam for electricity generation or for industrial processes, but it could also power microturbines and gas engines, and feed fuel cells. Pyrolysis involves the chemical decomposition of organic materials at elevated temperatures in the absence of oxygen to produce liquid, gas, and char. The resulting pyrolysis oil can be used in traditional power generation and heating applications with minor modifications.

There are also modular bioenergy systems, which are biomass energy systems (e.g., CHP, AD, gasification) at small scale used in off-grid, distributed generation applications. Combustion, CHP, AD, and low-percentage co-firing are mature, commercially available technologies whereas commercial gasification and pyrolysis are in earlier stages of development, demonstration, and deployment.

Biomass electricity generation accounts for 11% of all renewable energy generated in the United States and about 1.5% of total electricity generation (EIA 2014f). While the installed biopower capacity has been increasing over the past 10 years, biopower generation has remained almost flat during that period (Figure 33). The total number of biopower plants increased from 485 in 2003 to 673 in 2012 (EIA 2014g). In 2012, the states with the largest biopower installed capacity and generation were California and Florida (Figure 34). California has adopted many policies and initiatives to promote bioenergy (e.g., California Renewables Portfolio Standard, California Integrated Waste Management Act of 1989, Assembly Bill 341, and CalRecycle's Anaerobic Digestion Initiative), which has resulted in the largest and most diverse biomass energy industry in the country. Florida has a large biomass resource base and through industry-driven initiatives also has become a major biopower producer.

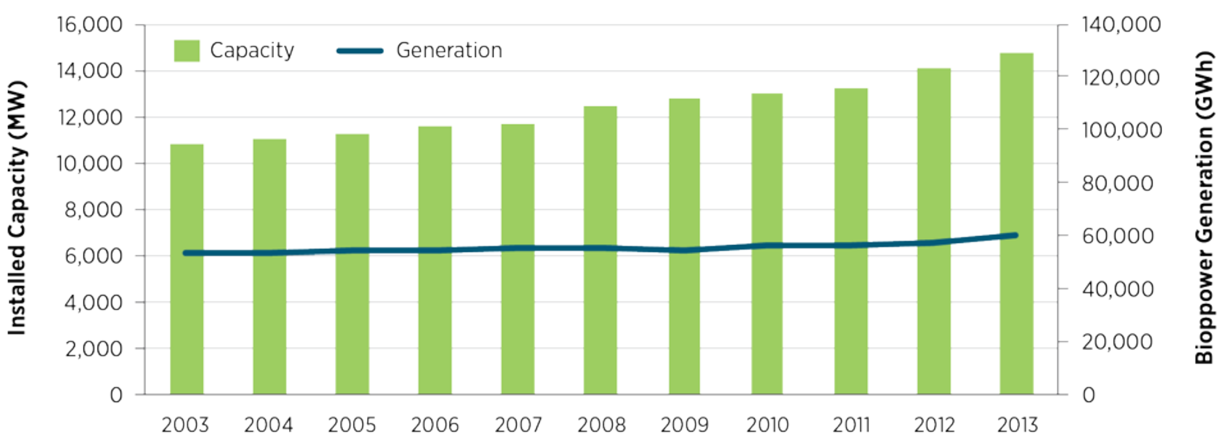

Figure 33. U.S. biopower capacity and generation

Source: EIA 2014f.

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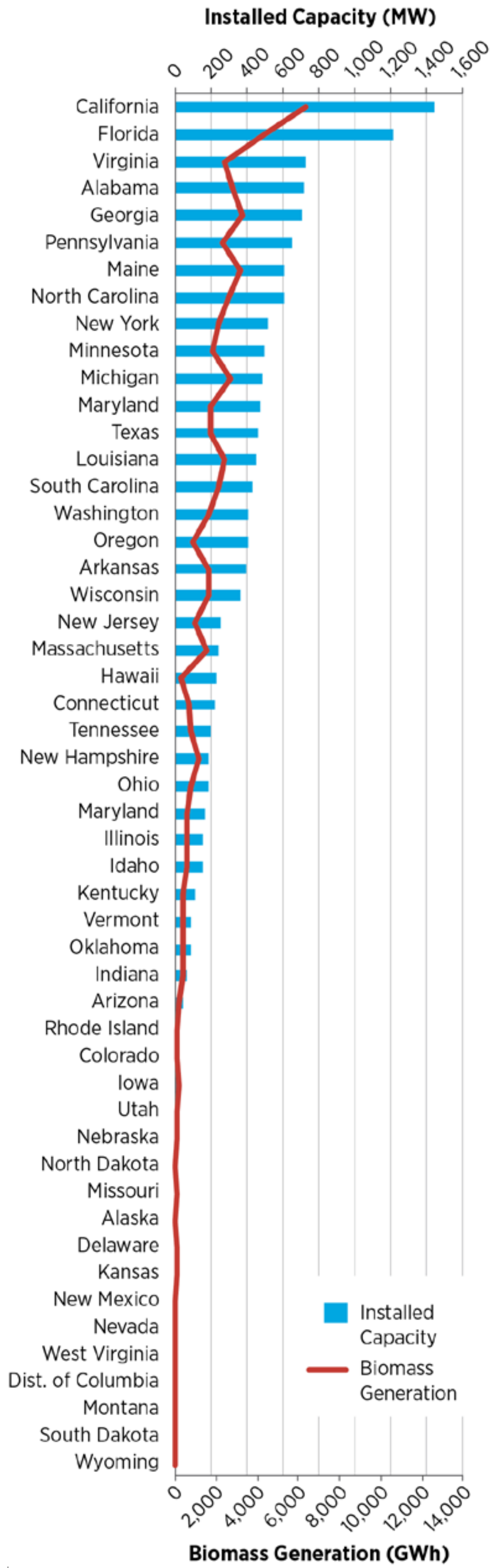

Figure 34. 2012 biopower capacity and generation by state

Sources: EIA 2014g and EIA 2014h.

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Biomass electricity is produced from various biomass resources. These include cellulosic material, biogas produced from landfills, wastewater, manure, and other organic wastes. Today, most of the biopower is generated from woody biomass (namely low-quality wood, residues, and by-products) in dedicated or cogeneration plants (such as pulp and paper mills or sawmills). Biogas is used to generate electricity for on-site use or sale to the grid and as a pipeline-quality gas (also called renewable natural gas). Wood and wood waste provided about 37% of total biomass power generation in 2013; black liquor provided 30%; and the organic portion of MSW provided 12% (Figure 35). While the use of these sources in biomass power applications has leveled over the past 10 years, the use of landfill gas (LFG) has been increasing—from 9.5% of biopower generation in 2003 to about 16% in 2013. The use of other biomass sources such as agricultural crop residues, sludge waste, other biomass solids, and gases remains very small in comparison (EIA 2014f).

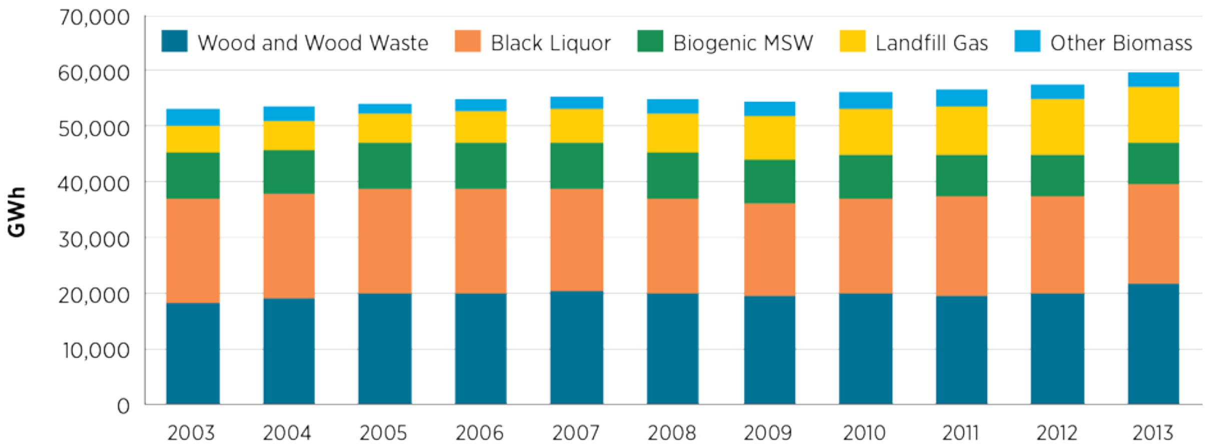

Figure 35. U.S. biopower generation sources

MSW = municipal solid waste. Other biomass includes other biomass solids, other biomass gases, agricultural crop residues, sludge waste, wood-waste liquids, and other biomass liquids.

Source: EIA 2014f.

Because of widely varying feedstock and conversion processes, there is a large range for the levelized cost of electricity (LCOE) of biomass power generation. LCOE is a calculation of the cost of electricity produced by a generator and includes capital costs, operations and maintenance (O&M), performance, and fuel costs (feedstock). The LCOE of biomass-fired power plants ranges from $0.04 to $0.29 /kWh (IRENA 2012). Direct combustion is reported to have an LCOE of $0.06–$0.21/kWh, co-firing LCOE is between $0.04–$0.13/kWh, landfill gas has an LCOE in the range of $0.09–$0.12 cents/kWh, and the LCOE for digesters is between $0.06–$0.15/kWh. The LCOE for CHP plants has an even wider range, for example, between $0.07–$0.29/kWh for stoker-fired CHP facilities. Feedstock costs typically account for between 20%–50% of the LCOE for power generation-only options, except co-firing (IRENA 2012). The wide range in feedstock costs is due primarily to transportation distances. For example, they can be zero for wastes that would otherwise have disposal costs or that are produced on site as a part of the industrial process (e.g., black liquor at pulp and paper mills or bagasse at sugar mills); they can be modest, where agricultural crop residues can be collected and transported over short

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distances; and they can be high, where significant transport distances are involved due to the low energy density of biomass (e.g., the trade in wood chips and pellets) (IRENA 2012). O&M costs are typically between 9%–20% of the LCOE for biomass power plants. They can be lower than that in the case of co-firing and greater for plants with extensive fuel preparation, handling, and conversion needs (IRENA 2012).

The biomass power industry provides many socio-economic benefits including job creation:

- It is estimated that a 50-MW dedicated biomass power plant utilizing direct combustion and using corn stover as feedstock could support about 25 on-site jobs during its operation (NREL 2014c).
- A typical 3-MW LFG electricity project directly creates five construction jobs and indirectly creates another 20 to 26 jobs during the construction year (EPA 2013). It also adds more than $1.5 million in new project expenditures and increases the statewide economic output by $4.1 million.

4.1 Biopower Outlook

In its 2014 Annual Energy Outlook, the EIA provides forecasts of the renewable energy generating capacity and generation, including biomass, all the way to 2040 (EIA 2014d). The 2014 AEO, in its reference case, projects that during the 2013–2040 period, co-firing will have the highest growth rate among all renewable energy technologies, about 14.5%. EIA assumed the existence and implementation of then-current state and federal regulations for emissions. The main driver for the projected increase in co-firing biomass is mostly economics, although in some cases it may be to comply with renewable portfolio standards (in some eastern states, co-firing is seen as potentially less expensive than building wind or solar facilities) (Namovicz 2014). In comparison, biopower generation by dedicated plants is projected to have an annual growth rate of 2.4%. Power generation from biogenic MSW is expected to remain almost flat during the period, with an annual growth rate of 0.5%. No significant increase in biopower capacity is projected.

5 Future Work

This initial market report will serve as a baseline for measuring the evolution of the domestic bioenergy market in future market reports. The data in this market report shows a flexible energy market adapting to emerging production of biofuels from a variety of feedstocks. It also documents the interplay of energy demand and regulatory aspects in driving the market. At the end of 2013, several companies were constructing biorefinery capacity capable of producing cellulosic biofuels at commercial-scale. Emerging market trends and commercial developments such as this example will be documented and examined in future market reports, relative to the baseline established by this market report.

In future years, the trends and observations contained in this market report will be updated as new datasets and market information become available. It also is envisioned that the scope of future reports will expand to capture and document emerging market trends. Specifically, documenting market information for bioproducts, including the wood pellet market, as well as chemicals derived from biomass that enable the economics and reduce risk to manufacturers for producing bioenergy will be captured.

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Appendix A: Relationship of *Billion-Ton Update* and *Bioenergy Market Report* Data

The purpose of this appendix is to establish the relationship between the data presented in the Feedstock Section of this *2013 Bioenergy Market Report* (BMR) and the data presented in the *2011 Billion-Ton Update* (BTU) (USDOE 2011). To establish this relationship, an adaptation of Table 2.1 from the BTU, which presents current and projected use of biomass resources, is included here as Table A-1. Table A-1 compares data from the "Current" column of Table 2.1 in the BTU with data on currently used biomass from Table 1 in the BMR. Some of the feedstock categorizations differed between the two reports, so best efforts were made in Table A-1 to correlate data between the two reports.

Table A-1 shows that specific values for some individual categories differ between the two reports due to differences in the source data used and methodologies applied for categorizing data. However, Table A-1 also shows aggregated values in reasonable agreement between the BTU and the BMR. While the BTU focuses primarily on future biomass feedstock projections derived from models, the BMR is based on feedstock resources reported in the open literature with a historical perspective up through 2012. The fact that the two reports use different approaches and arrive at relatively similar results helps validate the expected availability of biomass feedstock resources. Based on the comparison presented in Table A-1, the two reports can be viewed as complementary.

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Table A-1. Comparison of Biomass Feedstock Data Used in the *2013 Bioenergy Market Report* (BMR) and the *2011 Billion-Ton Update* (BTU) [Million Dry Tons per Year]

Source	Current Data from Table 2.1 of the BTU [Million Dry Tons per Year]	Comparative Data from Tables 1 and 2 of the BMR [Million Dry Tons per Year]	Comments
Forest			
Fuelwood	38	--	Fuelwood not included as biomass feedstock in the BMR
Mill Residue	32	60	BTU value compared to primary mill residues used for bioenergy (26 million dry tons) and fiber/other applications (34 million dry tons) in the BMR
Pulping Liquors	45	45	BTU value compared to black liquor category in the BMR
MSW Sources	14	11	BTU value compared to MSW wood used for bioenergy (1.9 million dry tons) and yard trimmings composted (9 million dry tons) in the BMR
Total Forest	**129**	**116**	
Agriculture			
Ethanol[a]	76 (109)	-- (130)	BTU value compared to starch-based biomass (namely corn) currently used for bioenergy in the BMR
Biodiesel	2	4	BTU value compared to lipid-based biomass currently used for bioenergy in the BMR
MSW Sources	7	--	MSW sources from agriculture not separately accounted for in the BMR
Total Agricultural Resources Currently Used	**85 (118)**	**-- (134)**	
Total Currently Used Resources	**214 (247)**	**116 (250)**	

Notes: In the BTU, fuelwood includes the residential commercial sector as well as biomass consumed by the electric utility industry in dedicated biomass plants and co-firing applications. MSW sources are allocated to forest (65%) and cropland (35%). Ethanol conversion calculations assume corn grain at 56 pounds per bushel, 15.5% moisture content, and 2.8 gallons per bushel. Biodiesel conversion calculations assume 7.5 pounds of oil/fats per gallon of biodiesel.

[a] From the BTU, the first number is the portion of corn consumed to make ethanol. The number in parentheses is the total amount of corn required. For example, it takes 109 million dry tons to make 13 billion gallons of ethanol. However, only 76 million dry tons are consumed to produce the ethanol. The remainder (33 million dry tons) goes to distillers grain.

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